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Best Practice Environmental Management: An Assessment of Implementation in Tasmanian Industry

By

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for the degree of Master of Environmental Management

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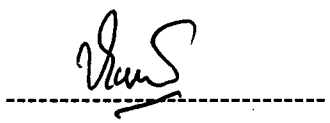
DECLARATION

I declare that this thesis contains no material which has been accepted for the award of any higher degree in any tertiary institution and that, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except when due reference is made in the text.



Virasack Chundara

30 January 2000

To my mother

ABSTRACT

The universal acceptance of the need for improved environmental management in all sectors of society has witnessed a plethora of approaches to achieve such ends. Central to the concerns over the continuing degradation of the environment has been the practice of industry and, in order for industry to reduce its impact on the environment, it is increasingly being required to accept and implement the concept of 'Best Practice Environmental Management' (BPEM).

The concept of BPEM focuses on three general principles. The first is the need for improved technology in both internal manufacturing and external effluent treatment processes. Such improvements may involve the introduction of best available technology or modifications to existing technology. The second principle consists of achieving consistently improved environmental performance through the improved management of industrial activities. This is largely achieved through the introduction of efficient and effective Environmental Management Systems (EMS). Best Practice Environmental Regulation (BPER) comprises the third principle which involves the identification of practices that have produced outcomes consistent with enhanced environmental performance and improved competitiveness.

This thesis assesses the level of acceptance and implementation of the concept of BPEM by using two of Tasmania's major industrial plants, Fletcher Challenge's pulp and paper mill and Pasminco – EZ's electrolytic zinc processing facility. Two definitions of the concept of BPEM are used for this assessment, one from Tasmania's resource management legislation, the other from the Australian Manufacturing Council.

Assessment of these two industrial complexes shows that management's acceptance and implementation of the principles of BPEM, as defined in the *Environmental Management and Pollution Control Act 1994*, has been substantial, and that significant improvements in environmental management have been achieved. The assessment also shows that these improvements have

coincided with the introduction of appropriate legislation. Conversely, it is impossible, from the data generated by the case studies, to assess the compliance of these two industrial facilities with the definition of BPEM used by the Australian Manufacturing Council. Furthermore, given the absence of prescription and capacity for interpretation allowed by the AMC definition, it may be argued that rather than a definition, the definition is merely a pointer towards the general direction of BPEM.

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1.1 Introduction

Global concerns about the effects of industrial development on the environment have intensified since the United Nations conference on the human environment held in 1972 in Stockholm, Sweden. These concerns, held by both the public and governments, involving the impacts of industries discharging toxic wastes into the environment, have forced industry to adopt a new approach to development. This new approach, based on the principles of sustainable development, is given the term 'Best Practice Environmental Management' (BPEM) (AMC, 1992).

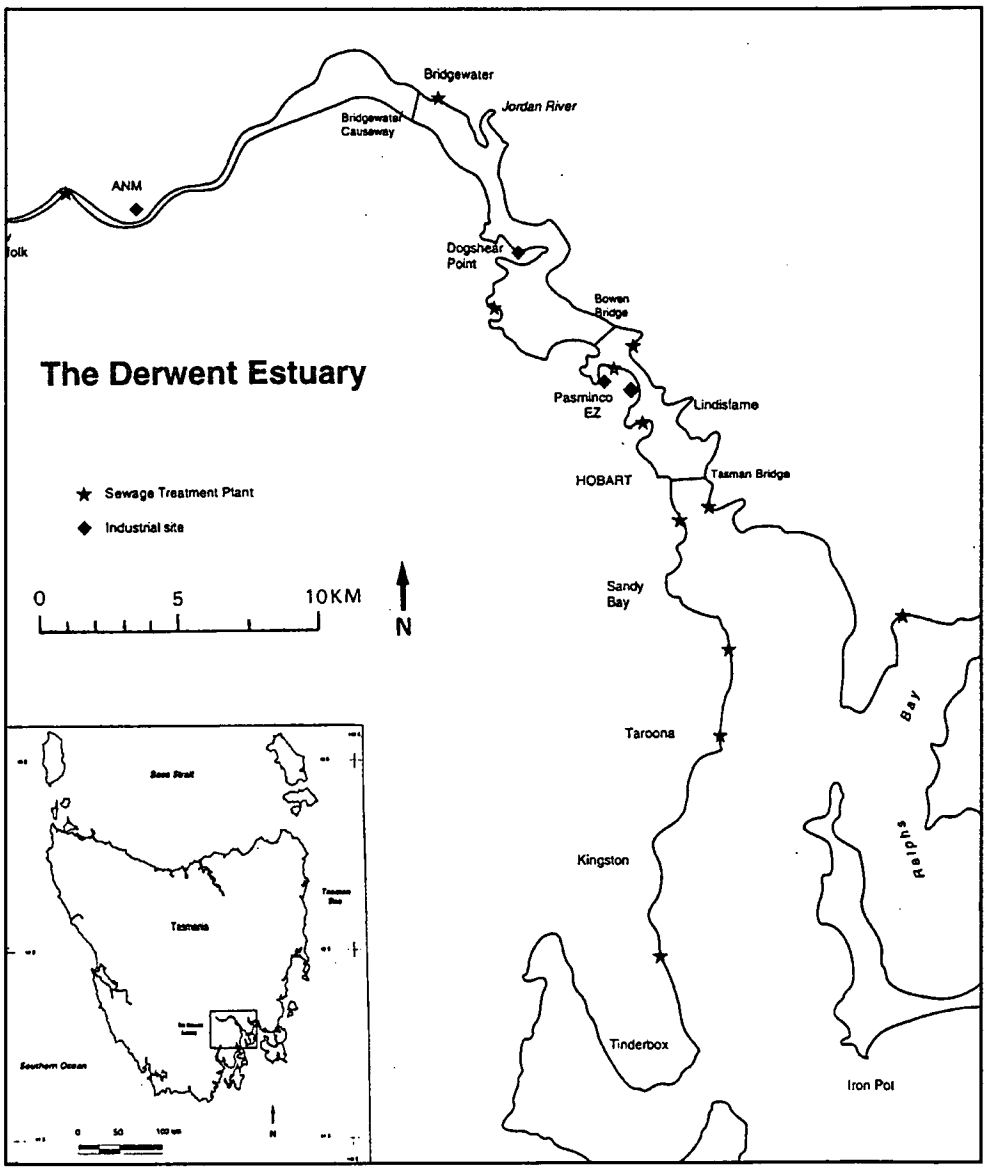
This thesis investigates the role of BPEM in relation to the environmental performance of two industries; the Fletcher Challenge pulp and paper mill at Boyer (approximately 20 km from Hobart) and the Pasminco Electrolytic Zinc Company (on the outskirts of suburban Hobart). Both industries are situated on the banks of the Derwent Estuary which runs through the City of Hobart (see Figure 1.1). The details of physical and chemical properties of the Derwent Estuary are summarised in Pirzl's (1996) thesis.

The Derwent Estuary is an important component of social and economic life in Southern Tasmania, as well as supporting significant ecological values. Socially, the Estuary, which flows through the centre of the City of Hobart, provides a highly valued aesthetic environment and a place for recreation and cultural activities.

There are many factors underlying the Estuary's economic significance for, not only southern, but also Tasmania as a whole. Two of the most important are the Estuary's role in aquaculture and tourism. The estuary also supports significant ecological values which, along with its social and economic roles, can only be fulfilled to the degree that the health of the Estuary is improved and maintained. In this respect the Estuary provides habitat for innumerable species of birds such as pelicans, black swans and must ducks. Furthermore, over a

hundred species of fish including migratory Australian salmon, gummy and school sharks have also been reported. It also provides habitat for many endangered and rare species of mammals including dolphins, whales (southern right, humpback and orca) and seals (Coughanowr, 1995).

Figure 1.1 The Derwent Estuary.



(Source: Pirzl, 1996).

Despite the Derwent Estuary playing this significant role it has been placed under considerable pressure from human activities primarily due to the expansion of suburbs and industries along its banks. The Estuary has been recognised as one of the most polluted estuaries in the world (Bloom, 1975). At

present, the Derwent is under pressure from numerous sources of pollution. The following sources of pollution in the Derwent Estuary are considered to be the main threaths to the Estuary's integrity:

1. **Light and Heavy Industry**, including sawmill effluent, organic effluent from the Cadbury plant, organic matter, chiefly wood fibre, small amounts of organochlorides, resin acids, mercury, and phenol from ANM Boyer mill, and heavy metals (arsenic, cadmium, copper, lead, mercury, and zinc) from the Pasminco-EZ plant at Risdon; and

2. **Recreation Sources**, including general litter, petrol from motor boats, exhaust fumes; and

3. **Municipal Council Sources**, including sewage effluent, storm water drains and urban runoff, additional sources of organic loads, metal and/or salt contamination, detergents, etc.

(Source: HECECT/Tasuni, 1989).

Although there are three dominant sources of pollution mention must also be made of the natural processes compounding these pollution issues. In this respect silt, sand, decomposing flora/fauna originating from the upper Derwent and Jordan Rivers, particulate matter and dissolved salts entering the estuary also have the potential to increase the pollution in the estuary.

This thesis focuses on how these two industries could improve their environmental performance by continuing with, or adopting, BPEM. This includes cleaner production that focuses on searching for better technology (by modifying internal manufacturing processes and external pollution control technology) and an improved environmental management system.

The thesis also includes, although this is not the responsibility of industry operators, discussion on the role of relevant legislation and regulation.

The conclusions from this study will benefit decision makers in industrialised countries and also those in developing countries presently

operating or planning to operate similar facilities. The conclusions will, for example, benefit the author's own country, Laos. Laos is a small country with a population of less than 4 500 000. Industrial development has rapidly increased since it opened its doors to the mechanisms of the world market in early 1990s. In Laos, although much legislation and regulation have been put in place, enforcement of the statutory requirements by command and control methods has not always succeeded. Perhaps encouraging industry operators in Laos to improve their environmental performance by self-regulation in accordance with the principles of BPEM may have greater success.

Although Laos does not presently have zinc processing or pulp and paper industries, the latter industry may be established in the near future. However, the focus in this thesis on BPEM principles and mechanisms is arguably more significant than the types of industry, as BPEM principles and processes can be applied to any types of industry. The author, as a Laotian government officer responsible for pollution control, can draw on the conclusions and experience gained from this thesis in relation to improving the environmental performance of industry in Laos in the future.

In addition, the thesis shows that the principles of BPEM that are widely accepted in Australia and internationally, are also useful in the Tasmanian environment, especially in relation to the Derwent Estuary. Encouraging industries to adopt BPEM principles and processes will also help them to maintain, if not increase, their economic competitiveness, increase their compliance with legislation and associated regulations, as well as achieving sound environmental performance.

1.2 Thesis Aims and Objectives

This thesis is an attempt to answer the questions: to what degree has Tasmanian industry accepted BPEM principles; and to what degree have these principles been implemented? To answer these questions the thesis assesses the environmental performance of two major Tasmanian industries in terms of:

- their adoption of best practice environmental management;

- the role of cleaner production, International Standardization for Organizations – ISO 14000 and regulation in BPEM; and
- the incorporation and role of technological processes and pollution control technologies related to pulp and paper industry and non-ferrous metallurgy industry (zinc refinery industry) in achieving BPEM.

Integral to and underpinning these aims and objectives is a historical review of the technological production processes and environmental control measures implemented at Fletcher Challenge's Boyer mill and the Pasminco Electrolytic Zinc Company.

1.3 Thesis Outline

The thesis consists of three main sections. Section One consists of Chapters One and Two. Chapter One introduces the context of the study and sets the aims and objectives. Chapter Two discusses the principles of BPEM, their roles and procedures. Chapter Two also discusses three principles for achieving BPEM. These comprise cleaner production, ISO 14000, and best practice environmental regulation.

Section Two consists of Chapters Three, Four, Five and Six. Chapter Three focuses on the technological processes of pulping and bleaching, the environmental impacts associated with pulping and bleaching wastes and the measures (both internal and external) to reduce the impacts of the production process on the environment. Chapters Four and Six respectively provide the case studies on the pulp and paper industry (Fletcher Challenge Boyer mill) and the Zinc Refinery industry (Pasminco Electrolytic Zinc Company). Included in these chapters is a historical review of the evolution of the technology developed and implemented at these plants. Chapter Five discusses the best available technological processes currently used in the zinc industry and its environmental protection measures. The discussion focuses on the roasting and bleaching technology for zinc concentrate (calcine), calcine purification, and zinc electrolysis. This chapter also focuses on the toxic wastes in the form of liquid effluents arising from this industry and the best available pollution control

technology to reduce the volume and toxicity of the wastes before they are released into the environment. The final chapter, Chapter Seven, presents the conclusions reached in this thesis.

1.4 Methodology

This approach to assessing the degree to which Tasmanian industry is employing BPEM is undertaken by comparing the available literature on BPEM with the findings from two case studies.

The case studies are used to determine the environmental management circumstances of two of Tasmania's major industries. The case studies focus on the Fletcher Challenge pulp and paper mill at Boyer and the Pasminco electrolytic zinc refinery. The information in these case studies was collected from published materials available in journals, on the internet, and from reports prepared by the companies and various State Government departments.

Inspections of these plants were also undertaken (Boyer mill 26/5/1999 on and PMEZ on 15/7/1999). These inspections provided invaluable information and allowed discussions with both management and production staff.

The information on BPEM was gathered from published materials and the internet. Two definitions of BPEM are used in this thesis: one is found in Tasmanian's resource management and planing legislation, the other is the definition used by the Australian Manufacturing Council.

Many obstacles hindered the comprehensiveness of the information that could be gathered. Information on best available technology, particularly in relation to zinc production processes and pollution control technology, is limited or unavailable. This is due to such information being largely confined within corporations who wish to avoid the contentious environmental issues associated with their operational practices.

Chapter 2

Achieving Best Practice Environmental Management

2.1 Introduction

Following the United Nations Conference on the Human Environment in Stockholm in 1972, global concern over the escalating degradation of the environment increased appreciably. These concerns led to numerous landmark publications such as the World Conservation Strategy and the Brundland Report, and culminated in the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 (Sitarz, 1994). The outcome from UNCED was that although economic growth must continue, development must meet economic and environmental needs (Sitarz, 1994).

It is clear that economic development must encompass the goal of sustainable development by adopting a new, broader approach to development. According to the UN, this approach must focus on cleaner production and environmentally sound technologies. In addition, the implementation of 'Environmental Management Systems' (EMSs) is important in enabling companies to respond efficiently and effectively to their sustainability challenges (United Nations, 1998). This new approach to development is termed 'Best Practice Environmental Management' (BPEM). BPEM is a strategy with roots in the concept of sustainable development, and is primarily intended to introduce organisational change. According to the AMC (1993), BPEM is an extension of advanced manufacturing techniques into environmental management. It is the 'application of soft and hard technologies to all manner of environmental issues in order to achieve the maximum continuous improvement for the minimum economic investment' (AMC, 1992: 11). The term 'soft technology' encompasses organisation and management of production and manufacturing, whereas 'hard technology' focuses on the production and manufacturing technology itself.

Under the Tasmanian *Environmental Management and Pollution Control Act (EMPCA) 1994* (EMPCA, 1994, clause 4(1)), BPEM is 'the management of

an activity to achieve an ongoing minimisation of the activity's environmental harm through cost effective measures assessed against the current international and national standards applicable to the activity'. By definition, it implies a path of continuous improvement in all aspects of environmental operation; environmental policy, planning, the implementation of environmental management programs, review and where necessary, modification to management practices. In determining the Best Practice Environmental Management for an activity, the *Environmental Management and Pollution Control Act 1994* requires that industries initiate the following measures:

a. strategic planning by the person carrying out, or proposing to carry out, the activity;
b. administrative systems implemented by the person, including staff training;
c. public consultation carried out by the person;
d. product and process design;
e. waste prevention, treatment and disposal

This definition of BPEM will be used in this thesis.

BPEM can be achived using several alternative paths. For this thesis, the author argues that BPEM can be broadly achieved through three principles: cleaner production, environmental management systems, and best practice environmental regulation (BPER).

2.2 Cleaner Production

Cleaner production is a new approach to development based on the concept of searching for technologies that will increase environmental protection and/or economic profitability. It involves the modification of internal manufacturing processes to allow for a more efficient use of raw materials, energy and natural resources, and the improvement of external pollution control technology to reduce pollution levels released into the environment. Cleaner production is the first step towards BPEM.

Although several terms have similar goals, that is, to improve environmental performance, terms such as clean technology, cleaner technology, waste minimisation and pollution prevention have narrow definitions when compared with cleaner production. For example, the traditional term 'pollution prevention' focuses on reducing the entire spectrum of pollutants released to land, and surface and ground waters. In terms of wastes, 'pollution prevention' focuses on treating wastes or their off-site recycling and/or disposal (DIR, 1996). By contrast, the term 'cleaner production' extends beyond pollution prevention. It does not simply focus on technology or a 'clear-cut set of generic technologies' to reduce pollution and control the disposal of hazardous or toxic wastes. It involves a new way of thinking about products and processes in a wider context by looking at means to reduce or eliminate the environmental impact of those products and processes (ANZECC, 1998).

The term 'cleaner production' was formulated by the United Nations Environment Program (UNEP) when it launched the Cleaner Production Program in 1989. It can be defined as 'the conceptual and procedural approach to production that demands that all phases of the life cycle of a product or process should be addressed with the objective of prevention or minimisation of short and long term risks to humanity and to the environment' (Hands et al., 1995: 63). Cleaner production specifically means:

- the continuous application of an integrated preventative environmental strategy to processes products and services to increase efficiency and reduce risks to humans and the environment;
- that production processes conserve raw materials and energy, eliminate toxic raw materials, and reduce the quantity and toxicity of all emissions and wastes before they leave the production process;
- that products have a reduced impact along the entire life cycle of the product from raw material extraction to disposal;
- that services associated with products have reduced environmental impacts across the entire life cycle of the product, that is from system

design and use to the consumption of resources required to provide the service; and

- the application of know-how, improved technology and changing attitudes.

(Source: UNEP, 1994: 3).

Adopting cleaner production entails moving forward from a purely technical 'end-of-pipe' focus to BPEM. This involves overhauling the total manufacturing process and its supporting systems. Such an overhaul can benefit both an organisation and the environment. Organisational benefits can include enhanced commercial competitiveness through a better public image, and an improved workplace resulting from the direct involvement of workers in continuously improving programs as well as their awareness of the processes, costs and environmental issues within the organisation. The benefits for the environment can include the reduction or elimination of: pollution through awareness by management of wastewater quantity and quality), air emissions and noise emissions, hazardous or toxic waste generation, and soil contamination. Through the efficient use of natural resources there can also be a reduction in greenhouse gas emissions, an improvement in product design and productivity, and a reduction of the unit cost of resource usage such as water and energy (UNEP, 1994; Anderson and Pagan, 1995; Gunningham and Sinclair, 1997).

2.2.1 Cleaner Production Overseas and in Australia

Cleaner production provides a means by which countries can protect both the environment and the community without compromising future trade or economic growth and development. The concept and technology of cleaner production has been widely recognised and accepted by many international groups including the United Nations Industrial Development Organisation (UNIDO), the Organisation for Economic Cooperation and Development (OECD), the World Business Council for Sustainable Development (WBCSD) and the Asia-Pacific Economic Cooperation (APEC) (Aquatech, 1997). Furthermore the concept and related technology is visible in many developing

nations such as Egypt and Tunisia in the Mediterranean region, Ethiopia and Tanzania in Africa, and Thailand and Vietnam in South-East Asia (Dowdeswell, 1996).

In Australia, the concept of cleaner production has been widely promoted in many jurisdictions and organisations, particularly in New South Wales, Queensland, South Australia and Victoria (Anderson and Pagan, 1995; Aquatech, 1997). Since 1989, the Australian Government has launched several programs to encourage cleaner production, either through specific cleaner production programs or through other mechanisms that promote and support the adopting of cleaner production. These include demonstration projects, providing information through publications, conferences, workshops or training, and by establishing the Australian Centre for Cleaner Production to provide and assist industry managers seeking the dual goals of international competitiveness and improved environmental performance through cleaner production (ANZECC, 1998).

In assessing whether an industry is adopting cleaner practices, certain criteria must be applied. An assessment must first determine whether modernisation or any environmental improvement programs with the potential for better environmental performance have been implemented. Such programs should focus on the efficient use of raw materials, reducing energy and chemical use, as well as reducing environmental emissions. For example, BPEM in the pulp and paper industry requires the modification of the bleaching process to allow for the use of new bleaching chemicals such as hydrogen peroxide and oxygen which result in reduced toxicity of pollution loads into the environment, and reduced energy and chemical consumption.

As the cleaner production philosophy focuses on only manufacturing technology processes, the implementation of cleaner production strategies alone could not lead industry to achieve the goal of BPEM. In addition to a cleaner production strategy, BPEM requires the implementation of environmental management systems.

2.3 Environmental Management Systems

The second fundamental component of BPEM is an effective and efficient environmental management system (EMS). These systems are intended to help companies manage, measure and improve the environmental aspects of their operations. An effective EMS can enable a company to not only efficiently increase its compliance with mandatory and voluntary environmental requirements, but also enhance its economic profitability by effecting a culture change in environmental management practices directly relevant to its overall business operations.

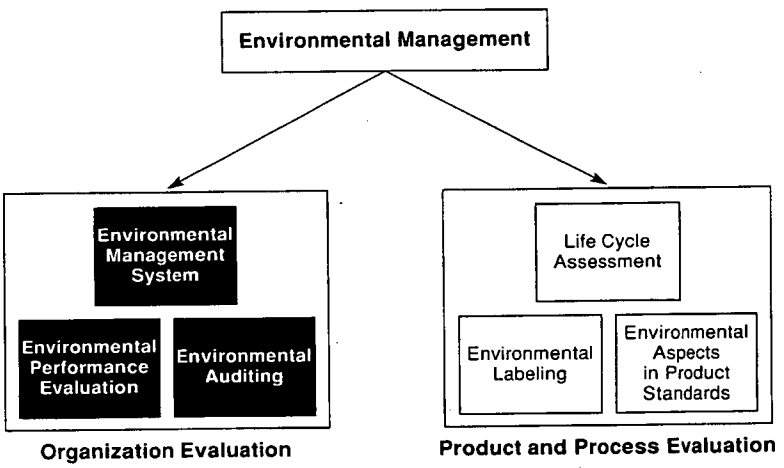
2.3.1 Environmental Management Standard – ISO 14000

There has been a proliferation of regional EMSs under different names, however, the International Organization for Standardization has provided a common international series of standards in an attempt to avoid the costs and trade difficulties of regionally incompatible systems. This series of standards, the ISO 14000 series, which is subject to ongoing development, has become an internationally recognised system for addressing environmental management. The ISO 14000 series is a system that will affect every aspect of a company's management of its environmental responsibilities. The management issues addressed by this series affect how a company: performs environmental auditing, measures environmental performance, lays claims for and analyses the life cycle of its products and processes, and reports environmental information to its employees and the public (Tibor and Feldman, 1996: 3). The series' standards are, in effect, to assist organisations to address environmental issues in a systematic way, thereby improving environmental performance.

It is essential to recognise that ISO 14000 standards are process rather than performance standards. In this respect the process standards offer companies the building blocks for a system that will help them achieve their own goals. In terms of BPEM, an EMS is the necessary tool for both identifying the opportunities for cleaner production and for articulating the compliance needs in relation to Best Practice Environmental Regulation. The ISO 14000 standards are underpinned by one fundamental assumption: that the goals associated with

environmental performance can only be attained through better environmental management.

Figure 2.1 Evaluation foci for environmental management



(Source: Tibor and Feldman, 1996)

The ISO 14000 standards describe the basic elements of an effective EMS. From Figure 2.1 it can be seen that environmental management in accordance with ISO 14000 has two separate evaluative foci. The first of these foci is the organisation where evaluation is undertaken on the organisation's environmental management system, environmental performance evaluation and environmental auditing. The second foci is the organisation's products and processes where evaluation is centred on an organisation's assessment of the life cycle of its products, environmental labelling and the environmental aspects associated with its product standards (Tibor and Feldman, 1996).

A brief outline of the two evaluative foci reveals how they are designed to achieve better environmental management. Organisational evaluation in relation to the environmental management system is undertaken in terms of an organisation's environmental policy which should give an overall sense of the organisation's direction and commitment to the environment and provide a framework for setting goals and objectives. Such policy should include a commitment to: continual improvement, pollution prevention, compliance with

relevant legislation, and provide a framework for setting and reviewing environmental objectives and targets. Planning is an integral component of the environmental management system and should allow an organisation to identify the environmental aspects of its activities, products and services that it can control and influence. Having identified such aspects the plan should determine which activities have significant environmental impacts, articulate the legal requirements that apply to the environmental aspects of those activities, products and services, and establish objectives and targets.

An organisation's planning should also encompass the means for implementing its policy and planning, and for evaluating its objectives and targets. This is dependent on the provision of a relevant management structure with competently trained personnel who understand their roles within the context of the EMS, are aware of the actual or potential environmental impacts of their work activities and are conversant with the relevant EMS policies and planning.

The second component of organisational evaluation focuses on an organisation's environmental performance evaluation. Such evaluation enables an organisation to use indicators to measure specific areas of performance such as the volume of waste produced per unit product, the percentage of recycled waste, pollution quantities, the level of wildlife habitat protection and the number of regulatory violations. The principal idea behind environmental performance evaluation is that an organisation can only manage that which it can measure. It is, therefore, imperative that personnel are competent in tracking and recording performance, understand the EMS objectives and targets and are conversant with operational controls.

The third organisational evaluation component concerns the environmental management system auditing procedures. Environmental management auditing can be defined as a systematic, documented, periodic and objective review by regulated entities of operational practices related to meeting environmental requirements (EPA, 1986: 25004). This is a system

rather than technical audit and is undertaken to determine the degree to which the EMS is conforming to the plans for environmental management, the level of implementation of the EMS, and the requirements of the ISO 14000 standard for environmental management auditing. The other important role of the audit is to provide management with the information to allow them to track the environmental performance of the EMS.

The second focus of organisational evaluation, that is, product and process evaluation, is concerned with product, process and service characteristics. Integral to this concern is the assessment of a product's life cycle from the initial raw material stage, through its production and distribution stages, to its possible reuse and disposal. Life cycle assessment is an approach for understanding the interaction between industrial activity and the environment. Its role is to highlight all the environmental aspects of an industry's operation so that the design of products and processes will improve manufacturing efficiency and economic competitiveness while simultaneously increasing environmental protection and conformity with environmental regulations. Central to product and process evaluation is 'full' or 'total cost accounting'. These methods 'allocate environmental costs, both direct and indirect, to a product, product line, process, service, or activity (Tibor and Feldman, 1996: 132).

The second issue connected with product and process evaluation is that of environmental labelling. Product labelling should provide clear and accurate information for consumers to make informed buying decisions. Accurate and standardised labelling allows the marketplace to be harnessed in favour of environmental protection through two mechanisms. Firstly, accurate, verifiable, relevant and non-deceptive labelling enables consumers to support those products which are accredited as causing less harm to the environment and, secondly, by encouraging other companies to follow suit and improve their products to gain accreditation to increase market share.

Meeting the ISO 14000 standards for product labelling indicates that a product meets the criteria of the labelling programme but it does not indicate that the product has been certified to product standards. The ISO 14000 series contains a plethora of product standards that have environmental implications and it is these standards which products must meet. Such standards are playing an increasingly important role in product design and development and becoming a useful tool for companies to improve their products, the efficiency of their production methods and the environmental aspects of their products. Such standards relate to the material and energy inputs of the product, the type and quantity of wastes generated during manufacture, the environmental costs associated with packaging, transportation and distribution, the options for reuse, recycling and repair or restoration and the options for disposal.

In concluding this discussion on ISO 14000 it is important to note that the standard does not require organisations to use Best Available Technology, even where it is economically viable. According to Tibor and Feldman (1996: 59) this would be a prescriptive requirement that reduced the flexibility of the standard, for example, by preventing an organisation from finding alternative ways to achieve its objectives. All that is required under the standard is that an organisation consider its technical options when setting its objectives and targets.

2.4 Best Practice Environmental Regulation

The two core principles of BPEM are cleaner production and environmental management systems. To encourage organisations to move torwards the goal of BPEM and to maintain their environmental performance, an external environmental tool, Best Practice Environmental Regulation (BPER) is required. According to AMC (1993: 9), 'Best Practice Environmental Regulation is the regulation that adopts identification of practices that have produced outcomes consistent with enhanced environmental performance and improved competitiveness'. BPER involves the identification of best practices (the modification of manufacturing processes and environmental management systems). BPER can be a tool that helps industries identify, compare and adopt

the best practice strategies of environmental management for their organisation. BPER has the potential to facilitate best environmental performance and increased economic competitiveness for complying industries.

In Australia, BPER principles are widely accepted. For example, the Federal Government has accepted that introducing legislation and regulation which facilitates competitiveness, international conventions and domestic environmental concerns can lead industries to the goal of sustainable development – BPEM (AMC, 1993). As a consequence the Australian Government has introduced a strategy for ecologically sustainable development known as the 'National Strategy for Ecologically Sustainable Development - NSESD'. The NSESD defines ecologically sustainable development (ESD) as 'using, conserving and enhancing the community's resources so that the ecological processes on which life depends are maintained, and the total quality of life, now and in the future can be increased' (Australia, 1992: 1). It sets out a broad strategic and policy framework for all State, Territory and local governments for pursuing ecologically sustainable development. In term of the strategy's impact on industries, it requires that State and local governments encourage industry to move torwards sustainable practices by adopting best practice environmental management and whole-life-cycle analysis (Australia, 1992).

2.5 The Resource Management and Planning System

In response to the NSESD, and in an effort to encourage manufacturing sectors to adopt sustainable development practices, the Tasmanian Government introduced a new resource management and planning system in 1994. The principal intention for the new Resource Management and Planning System (RMPS) was to integrate development and the environment. The RMPS promotes not only sustainable development within the State of Tasmania, but also supports the NSESD's aims of embedding the principles of sustainable development, via BPEM, in industry's activities.

The RMPS integrates five fundamental statutes in attempting to regulate development in terms of its environmental impacts. These statues comprise the *State Policies and Projects Act 1993,* the *Land-Use Planning and Approvals Act 1993,* the *Environmental Management and Pollution Control Act 1994*, the *Resource Management and Planning Appeal Tribunal Act 1993,* and the *Public Land (Administration and Forests) Act 1991.*

2.5.1 Environmental Management and Pollution Control

The Environmental Management and Pollution Control Act 1994 (EMPCA) is an integral part of the new Resource Management and Planning System, especially in relation to BPEM. The Act replaced the *Environmental Protection Act 1973* which was concerned with end of pipe pollution issues. The aims of EMPCA are to reduce the environmental impacts of industry by providing new and more effective development approval processes and provisions for enforcing statutory standards and regulations. The Act's objective is to promote sustainable development in the State. In this respect it provides for the control of all activities that might lead to environmental harm. This includes the promotion of pollution prevention, clean production technology, the reuse and recycling of materials, waste minimization programs, and the regulation of discharges of pollutants and hazardous substances to air, land or water consistent with maintaining environmental quality. A provision of the Act also allows the costs of environmental protection and restoration to be recovered from those whose activities result in environmental harm (Haynes, 1994).

2.5.1.1 Administrative Bodies

To encourage better environmental performance, the *Environmental Management and Pollution Control Act 1994* provides for 'environmental audits' to be voluntarily undertaken by industry managers seeking to improve their performance in relevant activities. Environmental auditing is 'a management tool comprising a systematic, documented, periodic and objective evaluation of how well environmental organisation, management and equipment are performing. The aim of the audit is to help safe-guard the environment by facilitating

management control of environmental practices, and assessing compliance with company policies which include meeting regulatory requirements. Environmental auditing is recognised by NSESD as a first step towards achieving improved environmental management (Australia, 1992).

Environmental audits can also be requested by the Minister responsible for administering the Act in circumstances where an industry has caused environmental harm (EMPCA, 1994).

Environmental Improvement Programmes are another feature of the *Environmental Management and Pollution Control Act 1994.* These are specific programmes designed to enable industry operators to achieve compliance with the Act by reducing environmental harm or complying with new environmental standards. The content of environmental improvement programmes specify the objectives to be achieved and maintained, and the time frames in which to achieve BPEM.

To secure compliance with the Act, the Board of Environmental Management and Pollution Control may require an operator to lodge with the Board a financial assurance in the form of a bond. The bond is to guarantee that specified actions are undertaken within a specified period to achieve compliance with the Act.

2.6 Conclusion

BPEM is the management of an activity to achieve an ongoing minimisation of the activity's environmental harm through cost effective measures assessed against the current international and national standards applicable to the activity. BPEM is the application of 'soft' and 'hard' technologies to all manner of environmental issues in order to achieve maximum continuous improvement for the minimum required cost. Achieving BPEM requires continuous improvement of all aspects of an organisation's environmental operation. Such improvements are needed in areas of environmental policy, planning, environmental management programs,

implementation and operation, checking and corrective action and review of management.

Cleaner production is imperative for achieving best practice environmental management. Adopting the principles of cleaner production involves adopting a new approach to development based on the concept of searching for better technologies that allow a more efficient use of raw materials, energy and natural resources while simultaneously reducing effluent emissions.

An Environmental Management System is an integral component of BPEM that enables organisations to utilise a systematic approach to evaluate their environmental performance. Adopting a continual improvement program such as the 'Environmental Management Standard - ISO 14000', which involves organisation evaluation and product evaluation, can benefit both the organisation and the environment. For an organisation, it can result in improved performance through the efficient use of raw materials, reduced energy consumption, enhanced public image and improved community and government relations.

Best Practice Environmental Regulation in the form of environmental legislation has been accepted as an effective tool by many governments to encourage industries towards sustainable development through the implementation of BPEM.

In Tasmania, the *Environmental Management and Pollution Control Act 1994* which addresses domestic environmental concerns and international environmental conventions has also been a precursor to industries in Tasmania adopting a new approach to development reflecting BPEM principles.

The pathway towards BPEM in Tasmania is to promote and adopt those technologies which are cost effective in producing cleaner products and allow for a continuing reduction in pollution. As is shown above, BPEM rests on the

implementation of both soft and hard technologies to encompass all facets of management and production.

The focus of this thesis is the pulp and paper and zinc industries in Tasmania. There are currently various technologies available for achieving BPEM in these industries. The following chapter discusses and evaluates the technologies relevant to the principal of BPEM in the pulp and paper industry, and the environmental parameters associated with pulp mill effluents, as well as the best available technology for pollution control.

Chapter 3
Technological Processes of Pulp Production

3.1 Introduction

Pulp and paper production generally comprises four principle processes: wood preparation, pulping, bleaching and paper production. In terms of environmental impacts from the toxicity of the effluent discharges from pulp and paper manufacturing, the impacts from wood pulp preparation and paper-making are substantially less than those from the pulping and bleaching processes (Biermann, 1993). In discussing BPEM in the pulp and paper industry, this chapter therefore focuses on these two latter processes, and briefly describes the main types of environmental parameters associated with these processes. The various pollution control technologies (internal and external treatment) that can be used to reduce the pollution loads on the receiving environment from pulp and paper production will also be evaluated.

The basic raw material for paper-making is cellulose in the form of fibres from a wide variety of plants. According to Casey (1960: 1) the raw materials can be obtained from sources such as cotton, straw and other non-woody plants, but wood is the primary source for modern paper-making industries. The two principal classes of wood usually used in pulp and paper production are gymnosperms (softwood) and angiosperms (hardwood). Hardwoods contain a higher percentage of cellulose and lower percentage of lignin than softwoods (Casey, 1960).

The initial phase of paper manufacture involves the preparation of pulp. This consists of two basic steps: the cooking of the raw materials followed by the purification of the pulp. In the cooking process, the raw materials are defibrated by various methods including pure mechanical, semi-mechanical and chemical means. In the process of pulp purification, pulp is subjected to bleaching and purifying agents to make the pulp more suitable for use. In any pulping operation, two of the main criteria used to assess efficiency are yield

and pulp strength. The general technological process of pulp production (chemical process) and its environmental impact is shown in Figure 3.1.

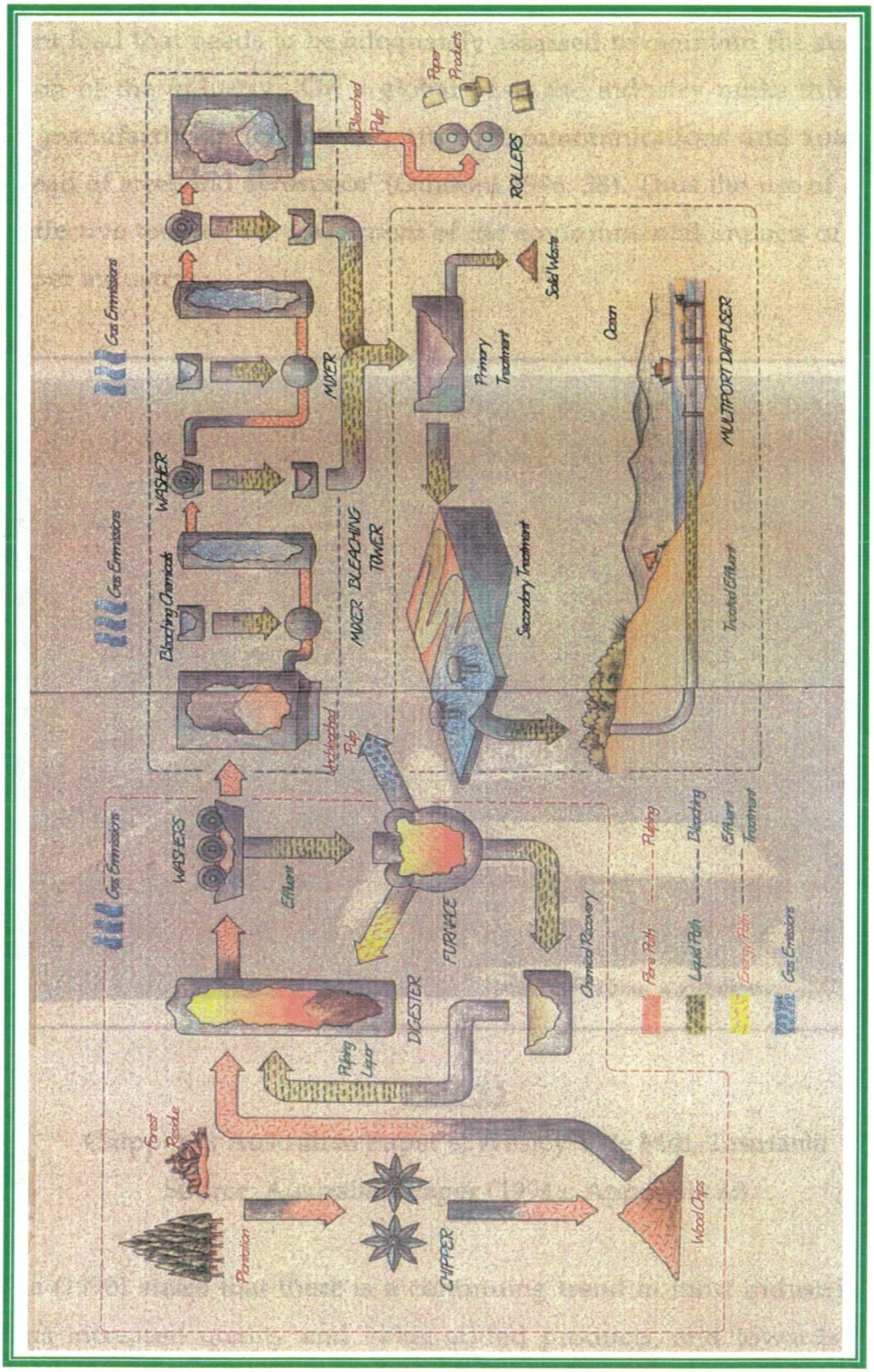


Figure 3.1 Chemical Pulping Process
(Source: National Pulp Mill Research Program, 1992: 2-3)

3.2 Pulping Processes

3.2.1 Mechanical Pulping

Mechanical pulping involves separating the cellulose fibres in wood by mechanical means (Simons, 1990: 72). It involves the reduction of wood to a fibrous state. Mechanical pulping is mainly used for softwoods. The earliest mechanical pulp mills used grinding stones to defibrate logs of wood for newsprint. Wood chips can also be defibrated in disc refiners to produce a pulp suitable for newsprint. Pulps produced by this process are usually characterised by high yields. However, mechanical pulps have lower strength than chemical pulps because the mechanical separation of wood components damages the fibres (Nelson et al., 1995: 7-8). Lignin is retained in the pulp. The total yield of pulp from the mechanical processes is about 90 to 98% of the raw material (Biermann, 1993: 63). Biermann noted that softwoods with light colour and non-resinous characteristics are usually used as a fibre source, however, spruce, balsam, hemlock and jack pine are seldom used due to their low pulp quality. Mechanical pulps are usually used for manufacture of newsprint, towelling, tissue, wall paper, and coated specialty paper (Springer, 1986: 146). In addition to the damage to the fibres from mechanical pulping another disadvantage with this process is its high energy requirement. Approximately 1200 to 2000 kWh is required to produce one tonne of dry pulp (Barker and Cullinan, 1989: 196).

Pure mechanical pulping processes have slowly been modified to improve the quality of pulp and reduce energy consumption.

The effluents from mechanical pulping vary greatly depending on the species of wood and the incorporation of temperature and chemical components in the process. In general, as can be seen in Table 3.1, increasing temperature and the use of chemicals increases the environmental parameters such as BOD_5 (biological oxygen demand) and COD (chemical oxygen demand).

Table 3.1 Summary of Pulping Processes.

Pulping Process	Wastewater loads (kg/ tonne pulp) COD	BOD_5
Stone Ground Wood (SGW)		
Unbleached	15-35	8-20
Bleached	20-40	-
Refined Mechanical Pulp (RMP)		
Unbleached	23.-55	12-25
Thermo-mechanical Pulping (TMP)		
Unbleached	40-45	10-30
Bleached	75-80	20-40
Chemi-Thermomechanical Pulping (CTMP)		
Unbleached	70-140	30-60
Bleached	80-160	40-85

(Source: Webb, 1992)

3.2.1.1 Stone Ground Wood (SGW)

Stone ground wood mechanical pulp is produced by grinding short logs on the tangential or radial surfaces of grinding stones (Kirkpatrick, 1991). Stone ground wood was first produced in the 1840s. The total yields produced by this process range from 93-98%, with energy use at about 1300 kwh/t (or 50-80 hp-day/ton) (Biermann, 1993: 63).

3.2.1.2 Refined Mechanical Pulp (RMP)

The RMP process was developed between 1948 and 1956 by the Baner Brothers. 'Refined Mechanical Pulp' is produced by disintegrating chips on revolving metal disks or plates at atmospheric pressure (Biermann, 1993: 67). The process usually consists of two stages. The first stage involves reducing wood chips to a coarse fibre by passing the chips with a stream of water through the fixed rotating discs of refiners. In the second stage, the coarse fibres are reduced to individual fibres (McCubbin, 1984: 17). At this stage, pulp is discharged from the refiners as a thick slurry and is screened and thickened (Springer, 1986: 148). Springer noted that fibres produced by this process are

stronger than those produced from the stone ground wood process because some of the steam generated in the process softens the incoming chips and the fibres maintain more of their original integrity. To produce one tonne of RMP requires 1600-1800 kWh or 90-100 hp-day/ton (Biermann, 1993: 67).

The Refined Mechanical Pulping process was historically popular. However, a modification of the RMP called 'Thermo-Mechanical Pulping', as well as continuing development of the mechanical pulping process, has made the RMP process almost obsolete.

3.2.1.3 Thermo-mechanical Pulping (TMP)

Thermo-mechanical pulping was introduced about 10 years after the RMP process and remains a popular process in many countries for manufacturing newprint (Springer, 1986). The basic principal of this process is to use temperature to soften or partially dissolve the lignin in the wood to enable the wood fibres to be easily separated (European Commission, 1994). According to Biermann (1993: 64), thermo-mechanical pulping is similar to the RMP process except that pulp is made in special refiners that are pressurised with steam at the refining stage. This stage has two phases. In the first phase, the refiners are operated at an elevated temperature of approximately 140°C and pressurised to promote fibre liberation: In the second phase, the refiners are held at an ambient temperature to optimise fibre characteristics for paper making (Biermann, 1993: 68). The TMP process produces a greater percentage of long fibres when compared with the RMP process, while the yields from the TMP process can be as high as 95% of raw material. The energy requirements to produce one tonne of dry pulp are, however, about 1900-2000 kwh/t or 100-150 hp-day/ton, slightly more than the requirement for RMP (Hoglund et al., 1997: 82-89).

3.2.1.4 Chemi-Mechanical Pulping

The original process of chemi-mechanical pulping was called the chemi-ground wood process when these chemical pretreatments were developed and stone ground wood was the predominant mechanical process (Biermann,

1993:69). In this process, wood is subjected to a mild chemical treatment before it is mechanically separated into fibres (Nelson et al., 1995: 8). The basic principal of CMP is to increase the strength of the pulp by removing some of the lignin from the wood before mechanical treatment. The total yields produced by this process are more than 85% for hardwoods and 90% for softwoods (Nelson et al., 1995: 8).

3.2.1.4.1 Cold Caustic Soda Process

Cold caustic soda pulping process (CCSP) was introduced in the early 1950s as a treatment for wood chips prior to the RMP or stone ground wood processes (Biermann, 1993). Biermann claims that by using this process prior to the SGW or RMP processes, the pulp attains a faster drain and can be used in faster paper machinery. The yield from the cold caustic soda process is approximately 80-95%. This method of pulping was popular in U.S.A. in the early 1960s, however, by 1970 only a few mills in the U.S.A retained this process (Biermann, 1993).

3.2.1.5 Chemi-Thermomechanical Pulping (CTMP)

Chemi-thermomechanical pulping is a similar process to TMP except that the wood chips are pretreated with small amounts (about 2% on dry wood) of sodium sulphite, sodium hydroxide or hydrogen peroxide in the alkaline peroxide method at elevated temperature and pressure prior to refining (Biermann, 1993: 70). The CTMP process has become popular because of the strength, versatility and high yield (90 to 92% compared with kraft at 40 to 42%) of the resulting pulp (Sinclair, 1990: 50). CTMP is used extensively in many countries for pulping softwoods, and is effectively used with most hardwoods, particularly in conjunction with the cold caustic soda process. It is, however, an unsuitable process for high quality paper because the alkalinity of the chemicals darkens the wood fibres (Fandry et al., 1989: 45). These authors (1989) also claim that the effectiveness of this technology on eucalypt wood chips is expected to provide the bulk of the raw materials for an Australian export pulp industry in the future.

Despite its effectiveness, there are major disadvantages with this process. These include low brightness (58-70% ISO brightness) and high-energy consumption for pulp production compared with other mechanically produced pulps (Kirkpatrick, 1991). The effluent resulting from this process is also more toxic (higher BOD_5) and its colour may be difficult to remove. Because of environmental concerns these factors have prevented this process from being used in many countries (Biermann, 1993).

3.2.1.6 Semi-chemical Pulping

The semi-chemical pulping processes use a combination of heat and chemicals in conjunction with mechanical pulping to remove some of the lignin in the wood (Nelson et al.,1995: 8). Semi-chemical pulping or high yield chemical pulping consists of two stages. The first stage involves softening the wood chips with chemicals, while the second includes the partial removal of both lignin and hemicellulose by refining (European Commission, 1994). The primary objective of this process is to obtain higher yields of useable pulp than can be obtained by the conventional pulping processes for hardwoods. The total yield from this process is approximately 60-80%.

The process referred to as 'cooking' uses sodium sulphite (Na_2SO_3) and sodium carbonate (Na_2CO_3) as a buffer in the cooking liquor by neutralising acids (European Commission, 1994). The European Commission notes that chemical recovery from this process is considerably more difficult than in the kraft process. In this respect, spent liquor is low in solids and contains a high proportion of inorganic and organic constituents which will not burn easily.

Semi-chemical pulp processing can be divided into two major methods, the neutral sulphite semi-chemical-anthraquinone and sulphite semi-chemical as detailed in the following sections.

3.2.1.7 Neutral Sulphite Semi-Chemical (NSSC)

The neutral sulphite semi-chemical process was developed in the early 1920s by the U.S. Forest Products Laboratory in Madison. The process was developed to obtain high pulp yields of 75-85% from hardwoods. The process

involves cooking wood chips in the presence of sodium sulphite and sodium carbonate at temperatures of 160-185°C (Biermann, 1993: 71). Biermann claims that the strength of the softwood pulp produced by this process is equal to that of the hardwood pulp and that both are stronger than kraft hardwood pulp. Energy consumption for this process is about 200-400 kWh/ton, which is extremely low compared to mechanical processes.

3.2.1.8 Neutral sulphite semi-chemical -Anthraquinone (NSSC-AQ)

The neutral sulphite semi-chemical-anthraquinone (NSSC-AQ) method is the NSSC process with an additional pulping chemical anthraquinone (AQ). This additional process was discovered in the late 1970s and is used as a catalyst to increase pulp yields without degradating the pulp properties (McCubbin, 1984: 29). The addition of small quantities of anthraquinone reduces energy consumption and chemical requirements by 1 to 2 %, and can increase pulping yields by a few per cent when compared to the semi-chemical pulping process. As a result, the pulping production rate is increased, however, the quality of pulp produced by this process is unsuitable for producing paper with a high brightness requirement.

3.2.2 Chemical Pulping

In the basic chemical pulping method, wood is cooked with chemical substances to a point where the fibres can be easily broken down and separated from other components of the wood (Nelson et al., 1995: 8). During cooking the chemicals react with the lignin in the wood and form a soluble compound which can be removed by washing (Bureau, 1989: 189). The yield percentages are, however, usually lower than for mechanical methods, ranging from 45 to 50% for conventional chemical pulps (European Commission, 1994).

According to Nelson et al. (1995: 8), most chemical pulps are self-sufficient in energy due to the recovery of large amounts of heat generated in the chemical recovery system.

Pollution loads from chemical pulping processes, however, are much greater those from the mechanical pulping processes.

Chemical pulping can be classified into two main methods, the sulphite and sulphate (kraft) processes. The main difference between the sulphite and sulphate process concerns the chemical used to dissolve the lignin.

3.2.2.1 Sulphite Pulping Process

Acid sulphite, used during the late 1800s and early 1900s, was one of the earliest large scale processes for the production of bleached wood pulp and during the late 1800s and early 1900s. Up until now it remains the dominant bleached chemical pulp process (Madden, 1991). The sulphite pulping process depends on the acidic effects of sulphur dioxide dissolved in a metal base (either calcium, sodium, magnesium, or ammonium hydroxide) on wood. The sulphite pulp is usually used for medium grade paper such as newsprint and writing paper. During the process, wood chips are cooked with chemicals at a temperature of 120-150°C for 2-3 hours (Biermann, 1993: 92). The total yield produced by the traditional sulphite process is about 50%. The advantage of sulphite pulp is that it is easy to bleach to high brightness using chemicals such as chlorine and hypochlorite. The disadvantage of sulphite pulp is that it has less strength than kraft or soda-AQ pulps (Madden, 1991: 85), and the process is not suited to mature hardwoods (Nelson et al. 1995: 8).

3.2.2.2 Sulphate or Kraft Process

The sulphate or kraft process is the dominant process in many countries. In this process, wood chips are cooked in a digester in the presence of strong alkali at an elevated temperature and pressure (Fandry et al., 1989: 46). This pulping technology, discovered in Germany in 1880, combines a sulphur compound (sodium sulphate) with caustic soda to produce a much stronger pulp than is available from other processes (Bureau, 1989: 184). The pulp strength results from these chemical substances dissolving the lignin without damaging the cellulose fibres (Fandry et al., 1989: 46). However, the recovery

rate of pulp from this process is relatively low, ranging from 45-55% compared with mechanical pulping (Bureau, 1989: 185).

Both unbleached and bleached kraft pulps have relatively long fibres and high strength. Unbleached kraft is usually used for lineboard, corrugated containers, bags, sacks, wrapping and industrial needs. Bleached kraft pulps are widely used for coated free printing papers, bond, reprographic, mimeograph, duplicating, envelopes, tablets and cover paper.

3.3 Bleaching Pulp

Bleaching is performed using chemicals to remove residual lignin from pulp. This is primarily undertaken to improve its brightness. The bleaching process undertaken depends on commercial requirements. Bleaching mechanical pulps is achieved by chemically altering the portion of the lignin molecule that absorbs light. Bleaching mechanical pulp is referred to as lignin preserving or 'brightening' to distinguish it from the bleaching of chemical pulp (Biermann, 1993: 123). Chemicals such as ozone, oxygen, hydrogen peroxide and sodium hydrosulphite are usually employed in this process.

According to Wartiovaara (1991: 97), the bleaching of chemical pulps is achieved by lignin removal which results in greater fibre-fibre bonding strength in paper, decreases the length of cellulose molecules and results in weaker fibres.

3.3.1 Bleaching Mechanical Pulp

The bleaching of mechanical pulp differs from the bleaching of chemical pulp in that the bleaching of the latter continues the chemical removal of lignin, then brightens. In contrast, mechanical pulps are brightened without any substantial removal of lignin or yield loss. The bleaching of mechanical pulps is based on brightening the pulp by modifying the lignin in the pulp to lower its colour (McCubbin, 1984: 73).

In recent decades, the bleaching of mechanical pulps has become popular for newsprint because of the decline in average wood quality

(increasing cost and the need to utilise non-ideal wood sources) and the increased use of TMP which is less bright than stone ground wood pulp.

Brightening mechanical pulps is undertaken with reducing agents such as hydrogen peroxide or hypochloride. The bleaching of mechanical pulp is usually carried out in a single or two-stage process. For example, hydrogen peroxide which will produce a brightness of approximately 60-70% is often used in a single stage process, where as 75% brightness can be achieved in a two stage process (Biermann, 1993: 123). The pulp brightness is also dependent on the wood species from which the pulp was derived.

Bleaching mechanical pulps puts significantly less stress on the environment than bleaching chemical pulps. This is because the bleaching of mechanical pulps can be carried out using less environmentally harmful chemicals such as peroxide, hydrosulphite and/or hypochloride depending on the level of brightness requirement.

3.3.1.1 Peroxide Bleaching

Bleaching mechanical pulps with hydrogen peroxide was first used in 1941 and the process has become widespread due to its effectiveness in preserving the yield of both mechanical and chemical pulps (Allison, 1983: 362).

Bleaching pulps with oxidative hydrogen peroxide is more expensive than hydrosulphite bleaching but produces a higher (up to 20%) and more stable brightness than hydrosulphite (McCubbin, 1984: 74). Although bleaching chemical pulp with hydrogen peroxide is less toxic compared to using elemental chlorine and chlorine dioxide, some studies have shown that the use of hydrogen peroxide to bleach mechanical pulps produces additional salts in the pulping effluent which, when discharged into rivers and lakes, raises salinity (Industry Commission, 1990: 32).

3.3.1.2 Hypochloride Bleaching

Hypochloride is used for bleaching mechanical and chemical pulps especially sulphite pulps. According to Wartiovaara (1993: 101), the oxidation

reaction of hypochloride is similar to the bleaching effects of chlorine, however, hypochloride oxidises the chromophoric group of the pulp, resulting in increased brightening. Hypochloride bleaching is usually carried out at 35-40 °C with a retention time of 1 to 2 hours with a pH > 9 (European Commission, 1994). Despite these advantages the use of hypochloride has decreased considerably during the last few years due to the handling difficulties at the high temperatures used in modern bleaching sequences and the high price (Wartiovaara, 1991: 101).

3.3.2 Bleaching Chemical Pulps

The bleaching of chemical pulps involves removing the residual lignin by treating the pulp with oxidising agents that break down the lignin structure and make it soluble in alkali (Nelson et al., 1995: 9). These authors believe that removing the remaining bundles of fibres as well as the remaining bark fragments with chemicals improves the paper 'printability' and absorbency.

Chemical pulp bleaching is usually carried out immediately after the washing stage using chlorine components or chlorine dioxide, oxygen or ozone.

3.3.2.1 Chlorine Dioxide Bleaching

The effectiveness of chlorine dioxide for bleaching has been known for many years and was first used commercially in 1946 (Britt, 1970: 275). Today, chlorine dioxide is substantially used to replace the chlorine in the chlorination stage, improving pulp strength, decreasing colour reversion and improving the recovery of bleach plant effluent. Chlorine dioxide is a yellow-green to orange gas with a disagreeable odour and is used in both pre-and final bleaching (Wartiovaara, 1991: 102). At high concentrations chlorine dioxide is an explosive chemical reagent if brought into contact with organic matter or ignited by electrical sparks (Casey, 1960: 497). Therefore, chlorine dioxide must be generated at the point of use and used immediately after generation (Wartiovaara, 1991). Bleaching with ClO_2 is usually carried out at high concentration at a temperature of 70-75 °C (European Commission, 1994). In the bleaching stage, the oxidation of lignin with chlorine dioxide is less effective

than with chlorine because the lignin aromatic phenolic group reacts with chlorine dioxide. However, lignification can be achieved by adding a small amount (up to 20%) of active chlorine. In the final stage, the use of chlorine dioxide to oxidise chromophores is very effective because chlorine dioxide reacts with only small amounts of carbohydrates (Wartiovaara, 1991: 103). Chlorine dioxide is increasingly being used to replace environmental chlorine in the initial bleaching stages because of its advantages in providing higher pulp brightness, improved fibrous strength and lower chemical consumption. Some data also demonstrates that substituting high levels of chlorine dioxide for chlorine in the bleaching process lowers the AOX level in bleaching effluents (Johnston et al., 1996; Kallvist et al., 1988). Some studies on the complete substitution of chlorine with chlorine dioxide show that the level of organochlorines are significantly decreased in such chlorine free processes and, because of their reduced environmental ramifications, have become the dominant process in many countries, for example in Sweden and Canada.

3.3.3 New Bleaching Technologies

3.3.3.1 Oxygen Bleaching

Oxygen bleaching has been developed into a viable and commercially proven process only in the last 20 years. It is most often used for delignification prior to bleaching with chlorine chemicals. The principal of oxygen bleaching is to reduce the chloride in the wastewater from the bleaching plant and to reduce the consumption of bleaching chemicals (McCubbin, 1984; Springer, 1986). Springer (1986: 171) notes that by using this technology about half of the lignin remaining in pulp can be removed without damaging the pulp strength or yield properties. However, in order to get environmental benefit from oxygen bleaching, the bleaching effluent must be sent to the pulp mill recovery cycle (McCubbin, 1984: 70).

According to Wartiovaara (1991), the reductions in effluent parameters from the bleach plant after 40-45% delignification are approximately 40% of COD, and 25% for BOD_5. Oxygen bleaching has become one of the main delignification technologies in many countries such as those in Scandinavia and

the United States of America. Its principal benefit is in reducing the demand for bleaching chemicals in relation to the kappa reduction (kappa is a number used to measure the lignin content of pulp; higher kappa numbers indicate higher lignin content). It also requires no other changes in bleaching technology.

3.3.3.2 Ozone Bleaching

The use of ozone as a bleaching reagent is relatively new, but is of significant commercial use for pulp bleaching in the paper industry. Ozone is currently used in 19 full-scale pulp-bleaching plants in countries such as the United States, South Africa and Brazil (EPRI, 1997). As a powerful and non-selective oxidising agent ozone can be used to selectively remove lignin and minimise cellulose degradation (Johnson, 1996). There are, however, several problems associated with using ozone as a bleaching reagent because ozone is very reactive during transport and storage. Consequently, the production of ozone must be confined to the mill, while it can only be produced in diluted mixtures with oxygen at concentration less than 60 g/m^3. Such large volumes of inert gas are difficult to mix with chemicals (Reeve and Earl, 1986), and the operating costs are high.

3.3.3.3 Enzyme Bleaching

Many alternative bleaching technologies have been proposed as a means for reducing the toxicity of pulp mill effluents and for bringing about the chlorine- free bleaching of kraft pulp. The bleaching of pulp using enzymes is one proposed bleaching technology. It is believed that enzymes which are biological (biodegradable) molecules can be used to either supplement or replace the chemicals in the bleaching process responsible for removing the lignin from wood chips. The use of lignin-degradable enzymes is expected, in the future, to bring about the chlorine-free bleaching of kraft pulps. Several types of enzymes, for example, xylanase, are known to act on lignin. However, to date their effects as a bleaching agent have been limited. Two alternative enzymes, manganese peroxidase and lacasse, may perhaps offer greater commercial potential, but several technological hurdles and a source for the enzymes are still to be overcome (Paice et al., 1995).

3.4 Environmental Parameters

The characteristics of pulp mill effluent differ from mill to mill depending on various circumstances such as the degree of cooking, which varies for the grade of pulp required, as well as the specific technological processes used in producing pulp. Several environmental parameters are used to assess the pollution load or effluent characteristics of pulp mill effluent. These include Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspend Solids (TSS), Absorbable Organic Halides (AOX), Acute Toxicity (LC50), Chronic Toxicity, colour, pH and temperature. These environmental parameters are discussed in sections 3.4.1 to 3.4.10.

3.4.1 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is the most widely used parameter measure organic matter. Biological oxygen demand is a measure of the capacity for effluent to consume oxygen when it is released into receiving waters. The oxygen in the receiving waters is consumed as a result of the microbial breakdown of the effluent's organic contents. Fandry et al. (1989) note that increasing levels of BOD in receiving waters decreases the water's ability to support aquatic life. Fandry et al. (1989) further claims that the bleaching plant is the greatest source of pollution.

3.4.2 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is the amount of oxygen required for the chemical oxidation of organic matter in wastewater. The COD test is carried out by oxidising a wastewater sample in the presence of a strong oxidant (dicromate, strong acid) (Fresenius, 1989). The author further claims that the ratio of COD and BOD vary due to the variability in the organic composition in wastewater.

3.4.3 Total Suspend Solids (TSS)

Pulp and paper wastes mainly consist of fiber and organic and inorganic matter derived from several production processes such as debarking, grinding

and/or washing. The environmental parameter TSS is used to measure the amount of matter suspended in a mill's effluent.

3.4.4 Absorbable Organic Halides (AOX)

The absorbable organic halides or chlorinated organic compounds (AOX) is 'the amount of AOX measured in a sample according to a standard test'. According to Fandry et al., (1989: 69), AOX is a significant environmental parameter in that it is used to determine the total amount of organochlorines contained in effluent. Young (1996) believes that AOX is equal to three times the total organochlorine (TOCL) load of the effluent. Absorbable organic halides are mainly derived from those plants where chlorine or chlorine based agents are used for bleaching (Samdani, 1991).

The significance of chlorinated organic compounds discharged into the environment is derived from their persistence and tendency to accumulate in the fatty tissue of living organisms (ANZECC, 1991).

3.4.5 Acute Toxicity (LC50)

Acute toxicity is 'toxicity occurring within a short period, often artibitrarily set at 96 hours' (Fandry et al. 1989:15). It is associated with resin, fatty acids and, to a lesser extent, chlorophenolic compounds (McLeauy, 1987). Although fatty acids and resin are biodegradable and their concentrations diminish during biological treatment (Industry Commission, 1990), McLeauy notes that the level of resin in untreated pulp mill effluents usually exceeds lethal limits. The total concentration of resins in whole mill effluents of untreated kraft effluents may range between 100-25,000 µg/L, while the resin concentration in untreated mechanical pulping effluents from ground wood mills may range between 13–80,000 µg/L resin.

3.4.6 Chronic Toxicity

Chronic toxicity is 'long term toxicity which may not manifest itself until many days or months after the exposure of organisms to toxic substances' (Fandry et al., 1989: 15). Chronic toxicity is associated with organochlorines.

These include the chlorinated dioxins, the chlorinated furans and the chlorophenolic compounds. The major source of chronic toxicity is from chlorine bleached kraft mill effluents (Industry Commission, 1990). Chronic toxicity remains a concern in both older and modern pulp plants. According to the Industry Commission (1990), the principal source of chronic toxicity is from organochlorines derived from chlorine bleached kraft mill effluents, or any pulp mill effluent originating from chlorine or chlorine-based based bleaching processes. Organochlorines are highly toxic and are 'considered to be the most hazardous group of substances for the aquatic environment' (Fandry et al., 1989: 15). Two main groups of 210 different isomers of dioxins are well recognised. These are polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzo-furans (PCDFs). However, only 15 isomers are believed to be toxic, with the most toxic representative being 2,3,7,8 tetrachlorodibenzo-para-dioxin (2,3,7,8-TCDD), and 2,3,7,8 tetrachlorodibenzo-furan ((2,3,7,8-TCDF) (Industry Commission, 1990; Kirkpatrick, 1991; Bonsor, et al., 1988: 21). As is noted above, these chlorinated dioxins have significant persistence and accumulation characteristics. They tend to accumulate in animal fat and in the environment for a long period of time.

Chlorinated dioxins cause a variety of sub-lethal effects, including 'histological change, metabolic, respiratory and behavioral effects, decreases in tolerance levels and primary productivity, growth and reproduction effects' (ANZECC, 1991: 17).

3.4.7 Colour

The colour of pulp mill effluent is another environmental parameter receiving much attention by the pulp and paper industry. The principal source of colour in pulp and paper making effluent is the lignin which results from the pulping, pulp washing, bleaching, spills and leaks (Springer, 1993). The amount of colour discharged from each source is further dependent on process conditions, such as temperature, pH, mechanical action and reaction of the wood with process chemicals.

Springer (1993) notes that discharging effluent with high colour into water bodies may cause negative effects on aquatic life systems, aesthetic quality, recreational use, light penetration, photosynthetic activity and oxygenation.

3.4.8 Mercury

Mercury is widely used in manufacturing sectors, including the pulp and paper and non-ferrous metallurgical industries. In the pulp and paper industry, mercury compounds are normally used as catalysts in chlorination, fungicides, slimicides or biocides (Patterson, 1985). This author further notes that the use of caustic soda, one of the products of the chlor-alkali process, may result in the formation of high concentrations of mercury in mill effluent.

Three important chemical forms of mercury occur in the environment: environmental mercury (HgO), divalent inorganic mercury (Hg^{2+}) and methyl mercury (CH_3Hg^+). According to Hart (1982: 166), methyl mercury is highly toxic to human and aquatic life. ANZECC (1992) notes that the total mercury concentration in fresh and marine waters should not exceed 0.1 µg/L, on the assumption that less than 10% of that 0.1 µg/L is in the form of methyl mercury.

3.4.9 Temperature

Temperature is a very important factor in water quality. Many physical, chemical and biological factors are influenced by temperature. While the temperature of streams is dependent upon on the depth of water, the season, and the time of day, there are also human activities which influence stream temperature (Cassidy, 1996).

The distribution and abundance of aquatic plants and animals changes as the temperature varies. Changes in temperature will alter the amount of dissolved oxygen in the water. It will also affect the rate of photosynthesis by algae and other plants (Cassidy, 1996). An alteration to ambient temperature can also affect the species exposed in a variety of ways; growth, metabolism, timing and success of reproduction, mobility and migration patterns (ANZECC,

1992). Cassidy (1996) notes that thermal stress can occur in animals and plants with water temperature changes of more than 1-2 °C in 24 hours.

3.4.10 pH

The term pH is used universally to express the intensity of the acid or alkaline condition of a solution. It is a way of expressing the hydrogen-ion concentration, or more precisely, the ion activity (Cassidy, 1996).

The pH of fresh water usually lies in the range 6.5 to 8.2, although wide variations can occur because of catchment geology. A range of factors including industrial runoff and sewerage can also affect the water pH (ANZECC, 1992). Changes in pH outside the normal ranges of water bodies will cause loss of the more sensitive species, with extremely high or low pH levels resulting in the death of aquatic life (Cassidy, 1996).

3.5 Pollution Control Measures

In light of public concern regarding industrial effluent, the pulp and paper industry has conducted research and has implemented ways of reducing organochlorine formation and other pollutants such as AOX, BOD and COD from mills. The reduction in the pollutants produced in pulp and paper manufacturing have been achieved through improved technology in both internal and external treatments.

3.5.1 Internal Treatment

Springer (1986) defines internal treatment as a modification of the process, which can be done by applying currently available technology, to make it non-polluting. Various process modifications have been implemented by the industry to reduce pollution loads arising from pulping and chemical recovery operations as well as resource consumption. The modifications to internal treatment process in order to reduce pollution loads are exemplified in the evolution of the delignification process. These modifications have included extending the period of delignification, substituting chlorine with chlorine dioxide, and using oxygen and hydrogen for delignification (bleaching).

Delignification using conventional procedures is slow, consumes a large quantity of energy, as well as leaving residual lignin which subsequently requires a large amount of chemicals for its removal.

Extending the delignification process has been shown to reduce these problems. In this respect, although over-cooking wood chips in order to remove the maximum amount of lignin can reduce the strength qualities of pulp, by introducing the bleaching agent anthroquinone it is possible to cook the pulp to lower kappa numbers without loss of pulp strength (Minor, 1982). In addition, extended delignification without loss of the pulp strength can be achieved by ensuring that the concentrations of cooking agents remain constant throughout the cook (Johnston et al., 1996). Substantial benefit is gained from extended delignification. When compared to traditional delignification practices, extended delignification reduces not only the quantities of chemicals required to produce pulps with a commercially acceptable brightness (Johnston et al., 1996), but also significantly reduces the pollution loads for external treatment while increasing the production of pulp per unit of raw material (Springer, 1986).

Substituting chlorine for chlorine dioxide, and using oxygen and ozone for delignification (bleaching) were discussed in section 3.3.2.1 to 3.3.3.2.

3.5.2 External Treatments

The liquid effluent from pulp mills usually requires additional treatment to remove undesirable organic compounds before it can be discharged into water bodies or courses. Such treatment is termed external treatment. External treatment is widely used for reducing the pollution loads from pulp mils, and consists of primary, secondary and tertiary treatments.

3.5.2.1 Primary Treatment

Primary treatment is accomplished using either mechanical means or settling basins. This phase of treatment is usually used to remove undesirable dissolved organic compounds. Using this method BOD can be reduced by 10% and 80-95% of settleable suspended solids can be removed using this treatment (Fandry et al., 1989). Settleable suspended solids are those solids

which will separate from the liquid after one hour of quiescent settling. Traditionally, the unit operations deployed in the pulp and paper industry are sedimentation, flotation, screening and media filtration (Edde, 1984). The time allowed for settleable solids (sludge) to deposit on the floor of the basin sedimentation is usually 6 to 24 hours (Bonsor et al., 1988). Sludge produced during the primary treatment can be disposed of by burning in the power boiler, or incinerated or deposited in landfills.

3.5.2.2 Secondary/Biological Treatment

Secondary treatment is designed to remove organic matter, BOD and organic compounds using a biological process. According to Fandry et al. (1986), approximately 70 to 95% of the BOD can be removed with this process. A significant reduction in AOX is also achieved with this process. With good design and operation, secondary treatment is believed to be able to significantly reduce AOX emissions and to eliminate acute toxicity and chronic toxicity in mill effluent (Industry Commission, 1990:106). Two main types of biological treatments exist: aerobic treatment with microorganisms requiring oxygen, and anaerobic treatment with micro-organisms working in the absence of oxygen. Anaerobic treatment has been generally found, however, to be unsuitable for treating pulp and paper mill effluents. Further, discussion of this method is unwarranted, but aerobic methods are discussed briefly below.

3.5.2.3 Secondary/Biological Treatment-Aerobic Methods

The aerobic methods comprising the secondary biological treatment consist of the aerated lagoon and activated sludge. Oxidation ponds (aerated lagoons) using oxygen from biological decomposition either through algal oxygen production or re-aeration at the surface air-liquid interface were, in the past, popularly used to treat pulp and paper mill effluents. However, the system has rarely been applied to treating pulp mill effluent in recent years due to its capacity for transferring oxygen into high colour pulping effluents (Edde,1984: 71). The limitations of oxidation pond technology have resulted in the development of the aerated lagoon. The retention times for the effluent range from 3 to 10 days (Springer, 1986: 234). Approximately 0.5 to 0.6 kg of O_2 is

required to remove kg of BOD_5 or 1.1 to 1.3 kg O_2/kg BOD_5 (Edde, 1984: 72). Transferring oxygen into the lagoon's effluent can be done by means of mechanical aeration equipment acting at the surface, by surface aerators or by diffusers. One such system proven through operation in Sweden can remove up to 60% of COD, 50 to 80% of BOD_5, and 25 to 30% of AOX (Bonsor et al., 1988).

The activated sludge treatment process involves the biological treatment of soluble organic compounds for conversion carbon dioxide, water and bacteria cells (Eckenfelder, 1981; Goronszy, 1991). The treatment system consists of two main units: the aeration basin, and the clarifier or sedimentation basin. The aeration basin is employed in the first stage to enable the introduction of biologically active material to increase the amount of suspended solids. The treated effluent is extracted and a portion of the sludge is returned to the aeration basin, with the excess sludge removed from the system (European Commission, 1996). Treatment efficiencies vary depending on effluent composition, plant design and operating conditions. Typical treatment values range between 85% to 95% for BOD removal, 40% to 80% for COD removal and 48% to 65% for AOX removal (Springer, 1986). The retention time for effluent in the system is about 2 to 6 days. Two types of activated sludge have been widely used. These are air-activated sludge and oxygen-activated sludge. In air-activated sludge, the effluent is aerated by natural absorption. By contrast, with oxygen-activated sludge, oxygen is supplied by mechanically introducing air with surface aerators or diffusers. This process allows large volumes of concentrated biologically active material to be treated in relatively short time periods (Edde, 1984).

3.5.2.4. Tertiary Treatment

Tertiary treatment means any treatment carried out as a post-treatment stage after biological treatment. Tertiary treatment can be used for further treatment and for removing suspended solids, residual BOD_5, nutrient, colour, organochlorines, and other toxic materials remaining in the effluent after primary and secondary treatment. Tertiary treatment includes activated carbon

absorption, massive lime treatment and foam separation (Keys, 1989: 22). However, these treatments have had limited use with pulp mill effluent as they are costly to operate (Bonsor et al., 1988: 93).

Although external treatments have been successfully used to remove residual wastes contained in pulp mill effluents, these treatments have not been able to remove the high levels of AOX from the wastewater. As a consequence, the sludge from treatment plants which is disposed in landfill or incinerated may contain up to 50g of AOX per kg of dried material (Johnston et al., 1996). The authors further note that biological sludge residue from the aerated treatment process ranges from 0-5 kg of dry solids per tonne of pulp and may contain between 2 and 30g AOX per kg. In activated sludge processes, 5-25 kg of sludge is produced per tonne of pulp with a content of 10-25 g AOX per kg. These figures indicate that external treatment may not be the best option for controlling pollution at pulp and paper mills. One possible solution is to move away from end of pipe treatments toward cleaner production, which in turn would enhance international economic competitiveness and lessen environmental impacts. Improvements can be achieved by modifying internal treatments, which in turn would reduce energy consumption, reduce the volume of toxic emissions. For example, a study which surveyed approximately 50 manufacturers across 6 countries showed that the longer an individual company made use of pollution reduction technology (e.g., extended delignification, Environmental Chlorine Free (ECF), and Total Chlorine Free (TCF) pulping processes) the greater the improvement in that firm's financial performance (Guidoni, 1996).

3.6 Conclusion

The core production processes in the pulp and paper industry are pulping and bleaching. Pulping processes can be divided into three main groups; mechanical, semi-chemical and chemical pulping.

Mechanical pulping involves separating wood fibres by mechanical or semi-mechanical means (stone ground wood, refined mechanical pulp,

thermomechanical pulp and chemi-thermomechanical pulping processes). Mechanical pulping is a high yield process resulting in retention 90%-98% of the raw materials. The process provides only low strength pulp, however, and consumes large amounts of energy (approximately 1000-1200 kWh/tonne of dry pulp).

Semi-chemical pulping (neutral sulphite semi-chemical and neutral sulphite semi-chemical–anthraquinone) uses a combination of heat and chemicals to remove lignin. Hardwood pulps produced by this process are characterised by lower yields (75%-85% of raw materials) than those from mechanical processes, and are stronger than kraft wood pulp.

Chemical pulping process result in lower yields (between 45%-50% of raw material), but bleaching these pulps is easier than those produced by mechanical and semi-chemical pulping. Chemical pulping processes are also relatively self-sufficient in terms of energy. Pollution loads from this process are, however, more toxic than mechanical or semi-mechanical pulping processes.

To achieve optimal pulp quality, all residual lignin contained in the pulp must be removed or bleached. In the past, the bleaching of mechanical pulps was not widely practiced. In recent decades, however, bleaching has become widely practiced due to the increasing use of mechanical pulps (which has low brightness) and the scarcity of raw materials. Chemicals used for this purpose are hydrogen peroxide, hypochloride or hydrosulphide.

The bleaching of chemical pulp is normally carried out using oxidising agents that breakdown the lignin structure making the pulps soluble in alkali. The chemicals used for this purpose are chlorine and chlorine dioxide. Chlorine was traditionally used as an oxidising agent in many mills but due to its toxicity (the formation of organochlorine compounds), especially in the aquatic environment, these chemicals have been banned in many countries.

The use of chlorine compounds as bleaching agents has been replaced by oxygen, a new and proven technology widely practiced in the pulp and paper industry. The use of oxygen in bleaching reduces both the chlorine pollution load in the wastewater and chemical consumption.

The bleaching of pulp using bleaching agents such as ozone and enzymes is relatively new. Ozone can, however, be used selectively to remove lignin and minimise cellulose degradation, while the use of enzymes in bleaching is also widely proposed as an alternative bleaching technology to chlorine or chlorine based technology.

Pollution loads from the pulp and paper industry vary depending on the grade of pulp required, the technological processes employed and the types of raw materials and chemicals used. However, pollution loads from this industry are generally characterised by high BOD, COD, TSS, acidity and alkalinity, temperature, resin acid, and/or organochlorine compounds.

To achieve better environmental performance in the pulp and paper industry it requires reducing pollution loads from plants, reducing the consumption of chemicals and energy, and minimising plant effluent. Such reductions can be achieved by both internal and external measures.

Improved internal measures require pulp and paper making processes to reduce the production of toxic wastes released from the plants. Implementing internal treatments such as extended delignification can help prevent the production of these wastes, while improving chemical recovery systems will reduce chemical consumption and also increase pulp quality.

External treatment is widely used to reduce pollutants from mill effluent. External treatment may involve primary treatment, secondary treatment and tertiary treatment. Primary treatment such as sedimentation, flotation and media filtration can usually be used to remove undesirable dissolved organic compounds. In this instance primary treatment will remove approximately 10% of BOD and 80%-95% of settleable suspended solids. Secondary/biological

treatments consist of using aerated lagoons and activated sludge process. Aerated lagoon treatment processes have been widely used to treat effluent from the pulp and paper industry. A well designed and maintained lagoon will remove up to 60% of COD, 50%-80% of BOD and 25% to 30% of AOX. Activated sludge treatments have been widely used for many years. The efficiency of this process varies depending on the effluents constituents, plant design and operating conditions. Typical removal values for BOD, COD and AOX are 85%-95%, 40%-80% and 48%-65%, respectively.

Tertiary treatment is normally used for further treatment and the removal of BOD, suspended solids, colour and organochlorince compounds. Tertiary treatment includes activated carbon, absorption, massive lime treatment and foam separation.

In this chapter various pulping and bleaching technologies including their characteristic emissions and treatments have been discussed and evaluated. The following chapter will introduce the case study of the pulp and paper mill investigated for this thesis. The use of this case study will also further investigate issues raised in the pulp and paper industry in relation to best available technology and best practice environmental management.

Chapter 4
Fletcher Challenge Boyer Mill

4.1 Background

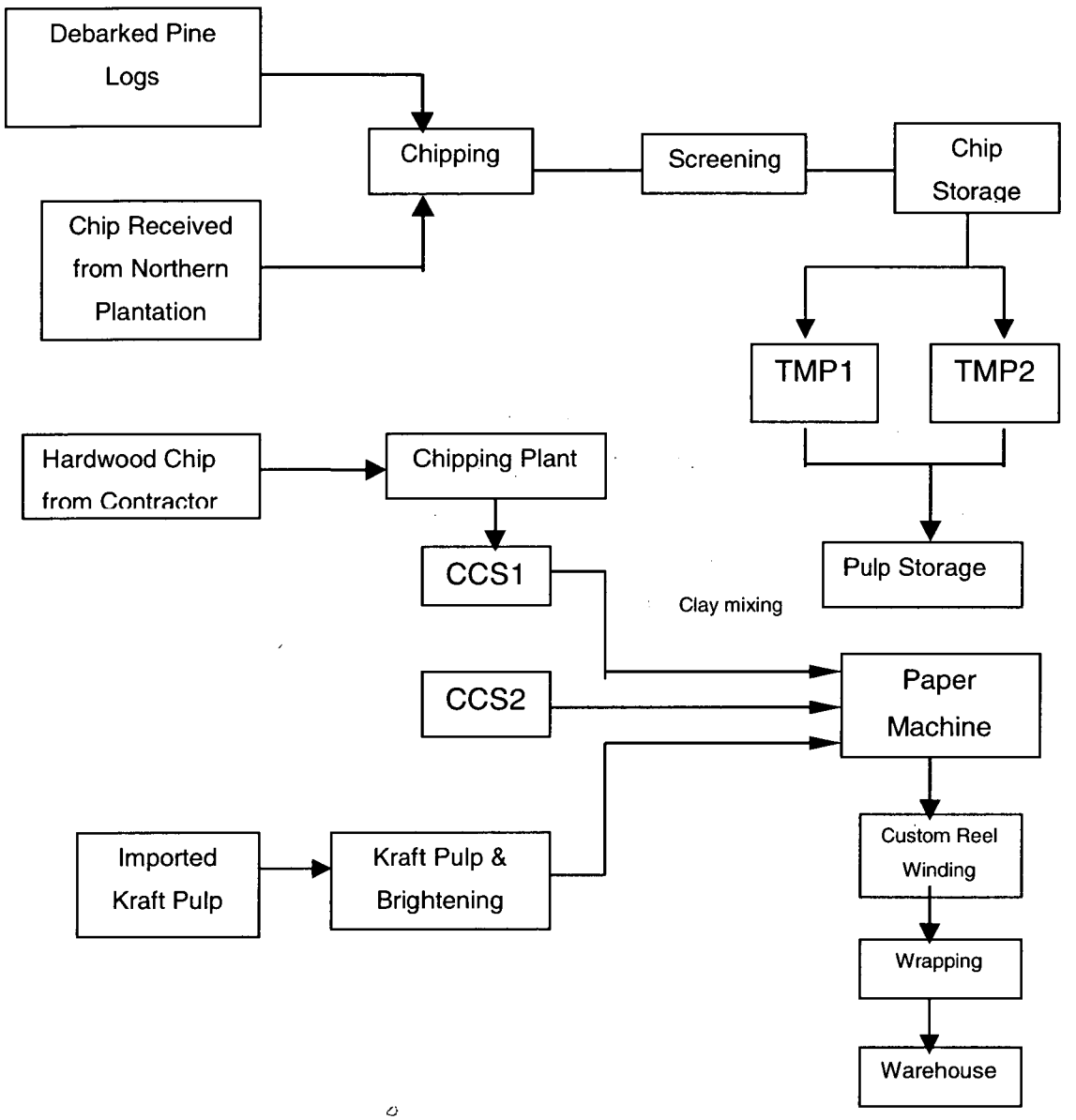
The Fletcher Challenge Paper (FCP) or Boyer mill, formerly the Australian Newsprint Mill (ANM), is situated on the northern bank of the Derwent River, 4 km downstream from New Norfolk and approximately 36 km upstream from Hobart. The Boyer mill is an integrated pulp and paper mill which commenced production in 1941. The principal reasons for establishing the mill in the New Norfolk area were the existing rail transport system which expediated the delivery of old growth eucalypt logs, and river transport for delivering the finished paper products to the port at Hobart.

Two main types of hardwood regrowth eucalypt and softwood pinus radiata are being used to produce pulp and paper at the Boyer mill. Hardwood chips from regrowth *Eucalyptus regnans*, *E.delegatensis*, and *E. obliqua* are used in the Cold Caustic Soda (CCS) plant, and softwood chips from *Pinus radiata* are used in the Thermo Mechanical Pulping (TMP) plant. Approximately 85% of the total requirement of 140 000 tonnes per year of hardwood eucalypt is supplied from the State Forest, and about 30 000 tonnes per year of radiata are being supplied by Forestry Tasmania and from private plantations located throughout the state (FCP, 1998). The various operations at the mill are summarised as follows:

- manufacturing pulp: two pulp streams are manufactured on site; Cold Caustic Soda (CCS) produced from eucalypt, and Thermomechanical pulp produced from pinus radiata. The third stream of softwood kraft pulp is imported.
- preparing of bleach liquor and caustic soda (sodium hydroxide).
- blending of the various pulp streams in a 'proportioner' prior to feeding to the paper machines.
- manufacturing white paper by two paper machines, reel winding, and wrapping.

A general schematic of pulp and paper production at the Boyer mill is shown in Figure 4.1.

Figure 4.1 General flow sheet of pulp and paper production at the Boyer mill



(Source: FCP, 1998).

The Boyer mill is the largest producer of newsprint in Australia. The annual production of paper at the mill has increased over the last decade. Total production at the Boyer Mill for the 1997/98 financial year was approximately 265 500 tonnes, of which 60% was white newsprint supplied to major Australian newspaper companies. Other products include newsprint, newsprint high

brightness paper, white directory, yellow directory, and coloured newsprint (FCP, 1998).

4.2 Brief Description of Pulp and Paper Production at the Boyer Mill

Over the past 60 years, the mill's pulping and paper machines have been extensively modified and upgraded to improve their capacity for paper production. The current technology for pulp and paper production at the mill is briefly discussed below.

4.2.1 Wood Preparation

Preparation of wood materials is the first stage of pulp and paper production. During this stage wood materials are debarked, chipped and classified before passing to the pulping stage. At the Boyer mill, the preparation of wood materials can be summarised as follows:

Regrowth Eucalypt: debarking of eucalypt logs is performed by private contractors before sending them to the mill. The debarked eucalypt logs are then chipped and the chips then classified by vibrating screen to choose the correct sized chips for the CCS pulping process. The oversize chips and slivers are removed as a waste and are sent to landfill.

Pinus radiata: approximately 30 000 tonnes per annum of screened radiata pine chips are supplied by sawmillers from the north-east of the State. The remaining portion of radiata pine is supplied as logs. In order to make suitable chips for the TMP pulping process these logs are first cut to about 3 m lengths before being sent for debarking, chipping and screening. In the screening stage, the chips are air-blown in pipelines to the TMP chip storage. Bark, sawdust and undersize chips are sold for horticultural use, while oversize chips are re-chipped before being returned for screening.

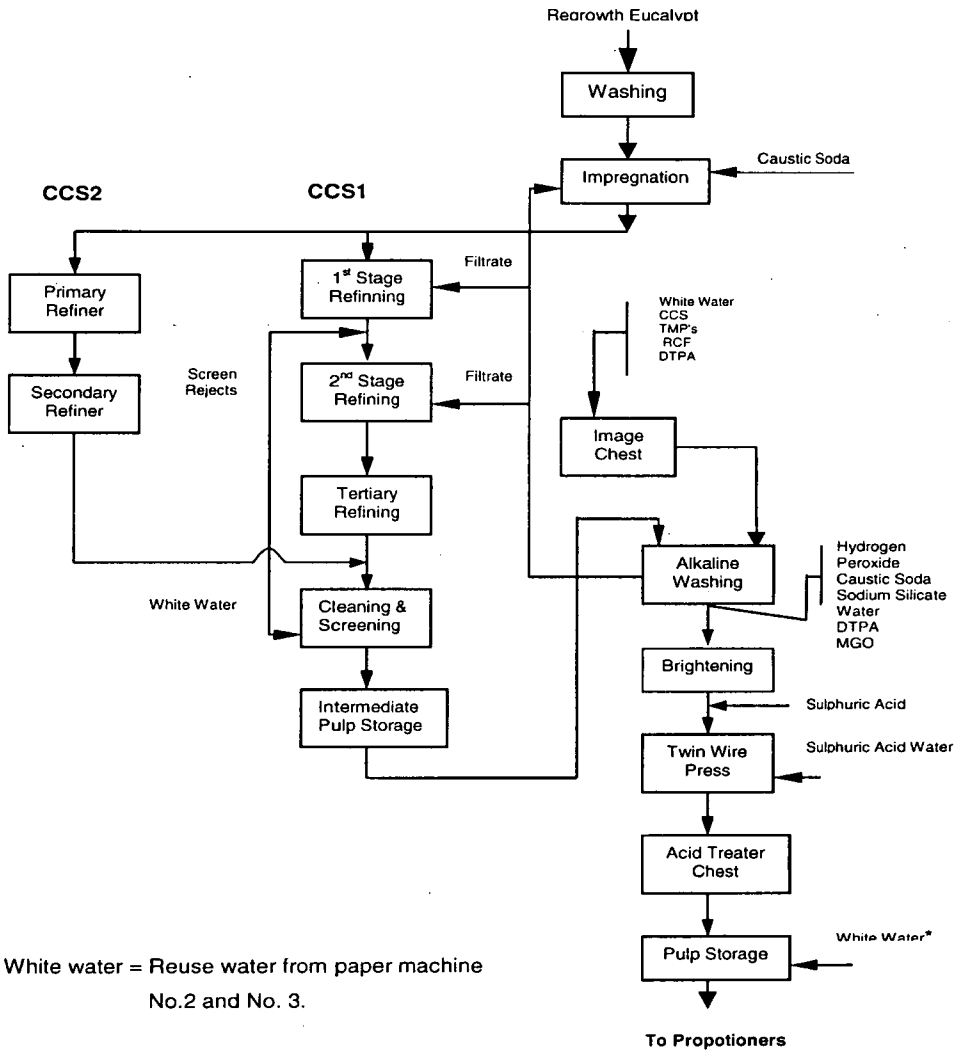
4.2.2 Pulp Production

4.2.2.1 Cold Caustic Soda (CCS) Pulp Production

In the CCS pulping process, eucalypt wood chips recovered from the storage silos are washed before being compressed and integrated with caustic soda solution which softens and allows better separation of the fibres. The

treated wood chips are then refined to separate their fibres. In CCS pulp production the refinery stream is separated into two independent paths. These are CCS1 and CCS2. According to Australian Newsprint Mill (1993), the CCS1 path comprises three primary refiners and four secondary refiners, while the CCS2 path has only one refiner at each stage. General flow sheets for the CCS1 and CCS2 paths are shown in Figure 4.2.

Figure 4.2 General Flow Sheets for CCS1 and CCS2 paths



(Source: FCP, 1998).

In the CCS1 pulp stream, after secondary refining, extractive colour is removed from the pulp by washing before brightening with calcium hypochlorite.

The brightening pulp is then treated with acid and washed again before entering the third refining stage. At this stage, a small amount of caustic soda is added to control pH to fully develop the pulp characteristics.

In the CCS2 pulp stream, after secondary refining, eucalypt pulp is washed, screened, cleaned and thickened. It is then brightened with hydrogen peroxide and other chemicals such as silicate, caustic soda, and with chelating agents which are added to optimise the brightness (FCP, 1998).

4.2.2.2 Thermo-mechanical Pulp (TMP) Production

In the thermo-mechanical process for both TMP No. 1 and TMP No. 2 plants, pine wood chips are washed and pre-heated with steam prior to primary refining. In the TMP plant No.1, after the pine wood chips are washed and pre-heated, they are agitated to relieve stresses built up in the fibres during the refining. The pulp is then post-refined for fine control of its properties, and screened at atmospheric pressure to remove undesirable debris (ANM, 1995). The rejected pulp from this stage is then further processed in the thermo-mechanical pulping plant No.2, and the accepted pulp is thickened and stored.

In the TMP plant No.2, after the pine chips have been washed and pre-heated, they undergo primary refining in double disc refiners under high pressure using steam. Approximately 15 tonnes of steam per hour is recovered and used for other heating processes around the mill. As with the TMP No.1 plant, before entering the bleaching stage, the pulp undergoes primary refining, post-refining, screening and thickening. General flow sheets for CCS1 and CCS2 are shown in Figures 4.3 and 4.4.

In the final stage, pulp from both TMP No.1 and TMP No.2 plants is bleached with sodium hydrosulphite to brighten it to market requirements (FCP, 1998).

4.2.2.3 Imported Kraft Pulp

The Boyer mill imports about 21 000 tonnes per year of unbleached and semi-bleached kraft pulp fibre in bales from New Zealand, the United States of America and Canada. The bales of imported kraft pulp are re-slushed in hydropulpers by agitating them in water.

4.2.3 Stock Preparation and Paper Production

Stock proportioning is a stage where various pulp streams are blended together in measured ratios. The mixed stock of pulp depends on various factors including the paper product being produced, available storage of pulp, the pulp production rate and the pulp quality.

To produce the higher brightness paper products additional brightening of stock may be necessary. To achieve this result, both CCS and TMP pulps are blended together before thickening and before brightening with hydrogen peroxide. Smalls amount of sodium silicate and caustic soda are added to maximise the hydrogen peroxide effectiveness and pH control.

Before the mixed stock is fed into the paper machines it is diluted, before cleaning in multi stage-cyclone cleaners and screens. Small amounts of calcined clay are added to the mixed stock to improve the printing quality of the paper products. The mixed stock is then fed through two machines, No.2 and No.3, which on average produce about 700 tonnes of paper rolls per day. The paper production is followed by customer reel wrapping, winding, and warehousing (FCP, 1998).

Figure 4.3 General flow sheet of TMP1

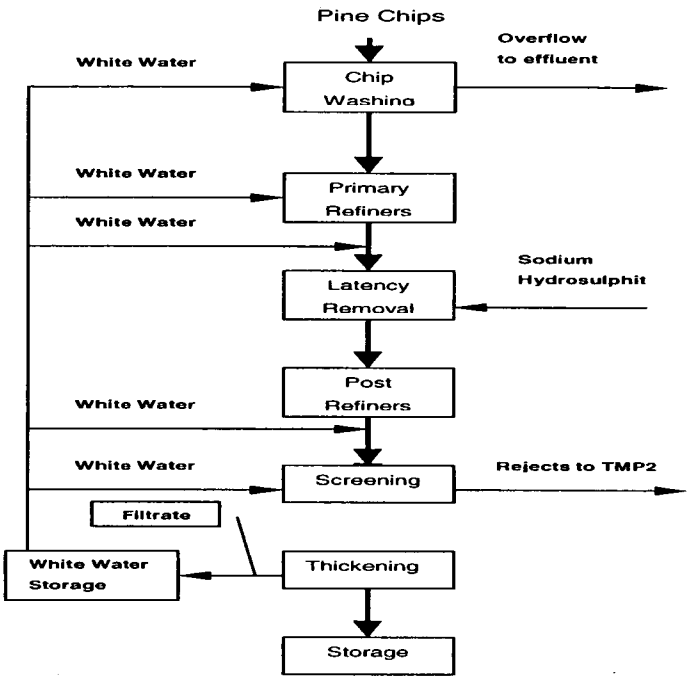
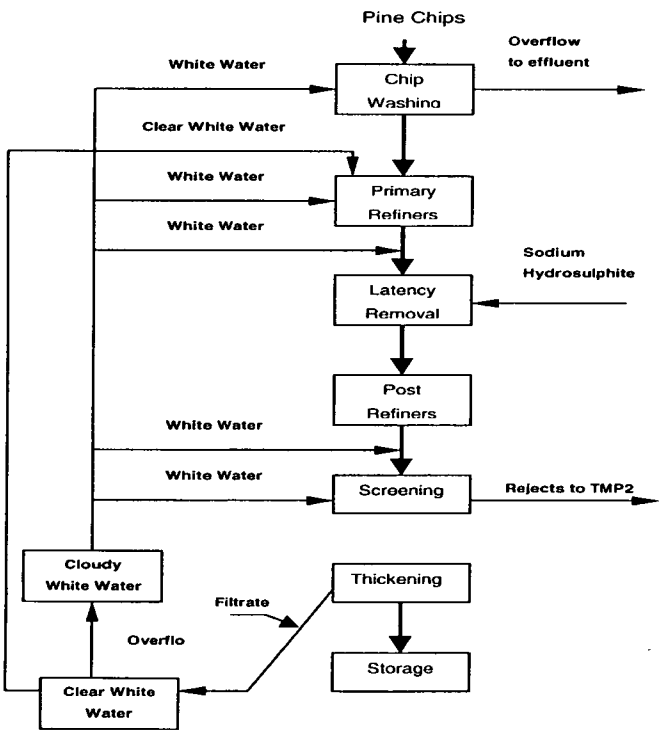


Figure 4.4 General flow sheet of TMP2



(Sources: FCP, 1998).

4.3 The History of Environmental Control Measures at the Boyer Mill.

The Boyer Pulp and Paper mill, like many industries located along the Derwent Estuary, has discharged a significant amount of pollution into the Derwent River as both atmospheric and liquid emissions. Atmospheric emissions have mainly derived from the coal-fired steam boiler No.5 and standby boilers, stockpiled dust, small amounts of gases released from chemical plants which produce calcium hypochlorite, sodium hypochlorite and hypochloric acid, and odour from hydrosulphite used as brightening agent in the TMP plant (ANM, 1993). The liquid emissions include the effluent from the pulp and paper processing plants, sewage effluent and storm runoff (Coughanowr, 1997).

Prior to 1990, four older boilers were used as a key part of the mill's paper production. Since these boilers did not comply with the permit limit of 0.25 g/m^3 (EPA, 1973), there was concern that particulate fallout would occur in areas surrounding the mill and on the opposite bank of the Derwent River. To address these concerns, a new $5.6 million coal-fired boiler (No. 5) with a three section electrostatic precipitator was installed in 1990.

The mill's effluent for 1993/94 is characterised by high temperature (about 30°C), high Total Organic Carbon (312 mg/L) content, high colour, low nutrient, and resin acids produced during the thermomechanical pulping process of pine (ANM, 1995). The use of the chlorine based compound, calcium hypochloride, for brightening pulps also resulted in the formation of a certain amount of the highly toxic chlorinated organic compound 2378 tetra-chloro dibenzo dioxin (TCDD) in the effluent. The Boyer mill's effluent is also characterised by high levels of organic matter measured as biochemical oxygen demand (ANM, 1993).

Up until 1987 the mill's effluent was directly discharged into the Derwent Estuary. Since 1941 the Boyer mill has discharged approximately 1.5 million tonnes of wood fibre into the estuary which has settled and combined with other organic materials to form around 4 million tonnes of gelatinous sludge which

extends downstream from Bridgewater to the Bowen Bridge close to areas of urban development (HECEC/Tasuni, 1989).

In response to the organic sludge issue, a $6 million primary clarifier effluent treatment plant was built in 1988 to reduce fibre loading into the estuary. Two years later, the second primary clarifier, which cost $8 million, was commissioned to further treat effluent. Both clarifiers have the capacity to remove, 90% of total suspended solids (TSS), 70% of BOD and 15%-20% of resin acids (Coughanowr, 1997: 48). With the commissioning of these two primary clarifiers, the Boyer mill has reduced its level of wood fibre released into the estuary from approximately 100 to 150 tonnes to only 4 to 5 tonnes per day (Coughanowr, 1997: 48).

Boyer's total effluent and effluent concentrations (of significant environmental parameters) as discharged into the estuary from 1987 to 1998 are outlined in Figures 4.5 and 4.6.

The Boyer mill, like many pulp and paper mills, is a great consumer of water. In 1990, water consumption was approximately 100 ML/day or around 140 m^3/tonne of paper produced. Recognising the need for natural resource conservation as well as increased economic competitiveness, in 1991 the mill's owners undertook a $66 million modernisation program. This involved installing multidisc filters 'savealls' and upgrading the production capacity of paper machines No.2 and No.3, a program which allowed the mill to reuse its processing water (white water). This reduced water consumption to about 60 ML/day or 85 m^3/tonne of paper. The future target for water consumption is approximately 40 ML/day.

The mill's effluent also contained a large quantity of chlorine and mercury used to breakdown wood pulp and to bleach newsprint. Prior to eliminating the use of chlorine based brightening chemicals and closing the caustic soda plant in 1992, approximately one tonne of chlorine and 85 kg of mercury were discharged into the estuary every year (Chapman, 1983: 52; Hanslow, 1994). In 1993, the mill's operators announced that they would eliminate the use of

chlorine based brightening chemicals and use a new bleaching chemical - hydrogen peroxide. The use of this environmentally friendly bleaching agent for all pulp has significantly reduced the amount of organochlorines released into the environment. The summary of major environmental improvements is shown in Table 4.1.

Table 4.1 Summary of major environmental improvements since 1988

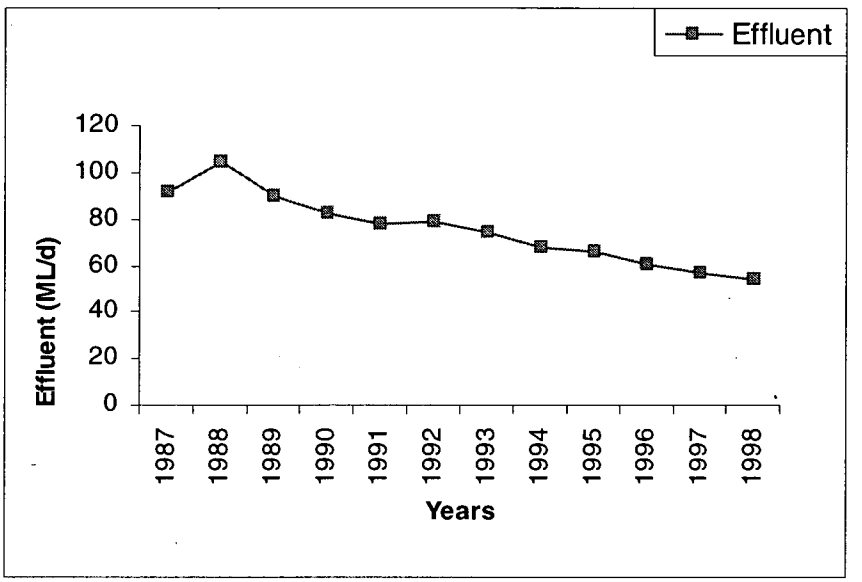
Year	Descriptions of Events
1988	commissioning of the first primary clarifier effluent treatment plant
1990	introduction of the second primary clarifier effluent treatment plant and a new coal-fired boiler No.5
1991	upgrading of paper machines No.2 and No.3
1992	closing of the caustic soda plant
1993	eliminating the use of chlorine based brightening

(Source ANM, 1993; ANM, 1995).

Storm water runoff from the site is another source of pollution into the estuary. Storm water runoff areas at the mill have been divided into three main zones: the western sector (Zone 1), the central area (Zone 2), and the northern area (Zone 3). Several measures have been implemented to manage storm water runoff from these sectors. These include collecting and treating the runoff through the construction of wetland and pond systems to divert runoff from the western sector and the construction of spill ponds to collect storm runoff from the central sector. Runoff from the log handling and chipping activities (the northern sector) is fed directly into the combined effluent stream (ANM, 1995; Coughanowr, 1997: 48).

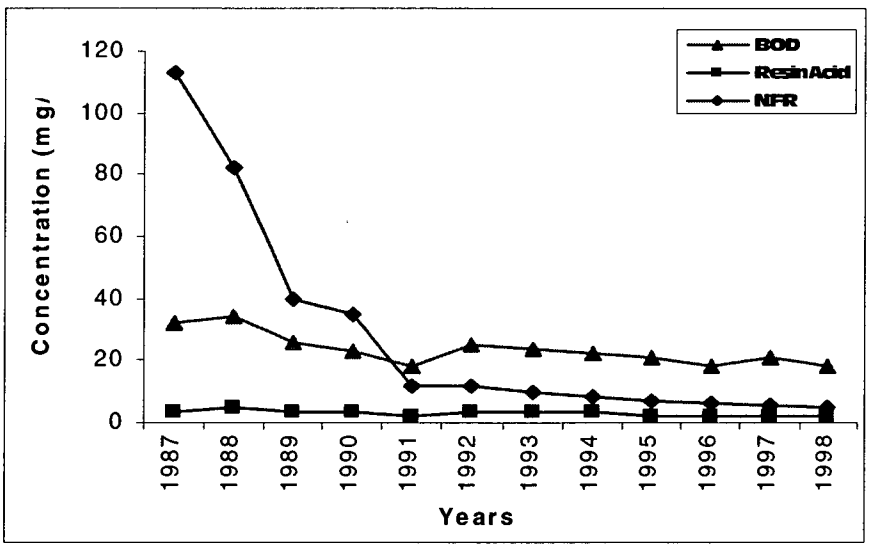
The implementation in 1990 of an 80 kL/d ultraviolet disinfection sewage treatment plant to replace 11 septic tanks in 1990 is another environmental measure which resulted in significantly decreased levels of coliforms from about 180 to 50 per 100 mL released into the estuary (FCP, 1998).

Figure 4.5 The average effluent discharge into the estuary



(ANM, 1993; ANM, 1995 and FCP, 1998).

Figure 4.6 Annual average of BOD_5, Resin Acid, and Non-Filterable Residue (NFR) (t/d oven dry), discharged into the estuary



(ANM, 1993; ANM, 1995 and FCP 1998).

Figures 4.5 and 4.6 show that the overall trend in average effluent flow, BOD emission, resin acid and non-filterable residue for the last 12 years has steadily declined following commissioning of clarifier No.1 in 1988 and the installation of clarifier No.2 in 1991.

Since 1996, numerous monitoring programs have been implemented at the mill. These include daily and weekly monitoring of the mill's combined effluent stream outfall for temperature, pH, TSS, BOD, resin acid and non-filterable residue. The mill has also introduced an intensive water monitoring quality program on the Derwent Estuary for temperature, pH, salinity, DO, resin acids, nutrients, and light penetration. Air emission testing on particulates and CO_2 at boiler No.5 is also carried out continuously (FCP, 1998; Coughanowr, 1997).

Over the last few decades the environmental performance of the FCP's Boyer mill has improved significantly. A wide range of environmental measures have been implemented. As a result, the Boyer mill has improved its environmental record. The modification of internal and external processes has led to the relatively efficient use of raw materials, water and energy and has reduced the levels of environmental emissions.

4.4 Environmental Management Systems at the Boyer mill

FCP Boyer mill has recognised that environmental management systems can provide a framework for measuring its environmental performance in relation to its protection of the environment, and improved its business competitiveness. In recent years, environmental management systems based on British Standard BS 7750 were implemented at the Boyer mill. The main objectives of this standard were to:

- identify and assess the environmental effects arising from the mills;
- identify the relevant regulatory requirements;
- enable priorities to be identified and pertinent environmental objectives and targets to be set;
- provide a documented system of procedures, responsibilities and instructions; and

- facilitate planning, control, monitoring, auditing and review activities.

Based on British Standard BS7750 requirements, FCP Boyer mill has produced an internal environmental management manual (FCP, 1998) which outlines its areas of responsibility for regulation and permit requirements, objectives and targets, registering of monitoring and control activities, and requirements for record management and environmental audits. To achieve the goal and objectives that were set in the internal environmental management manual, FCP's Boyer mill has provided formal and informal training programs for all employees and staff. These programms were held to ensure that the mill's operations complied with all legal requirements as well as with the environmental goals determined from audits conducted both internally as well as by external organisations.

In recent years, FCP's Boyer mill has taken a further step towards improving its environmental performance through adopting a new environmental management system ISO 14000. According to FCP (1998), all the formal processes of the environmental management system, British Standard BS 7750 already established at the mill will be integrated and used as a basic model for integration into ISO 14000. The integration into the new environmental management system is currently being investigated. At present, FCP's Boyer mill does not hold formal accreditation for ISO 14000.

The following chapter discusses and evaluates the technologies relevant to the principal of BPEM in the zinc refinery industry, and the environmental parameters associated with effluents of zinc refinery facility, as well as the best available technology for pollution control.

Chapter 5
The Metallurgy of Zinc and Pollution Control

5.1 Introduction

Zinc, a silvery white metal with low melting and boiling points was first used as a component of brass, a zinc-copper alloy, more than 2000 years ago (Zaitsev and Margulis, 1985). The smelting of zinc from ores probably originated in China in the third century BC, but it was not until the middle of the eighteenth century that the commercial production of zinc began in Europe. The first commercial process was developed by William Champion at Warmley, near the English town of Bristol, in 1746 (Morgan, 1977). Zinc production increased in the late eighteenth century following Ruberg's development of the first horizontal retort method. However, this method soon became obsolete with the developments of new methods of zinc production which introduced vertical retort and electrolytic processes. Zinc is widely used today for galvanising iron and steel used in large-scale construction projects, motor vehicle bodies, roof sheeting and other construction materials due to its high resistance to atmospheric corrosion.

5.2 Characteristic of Zinc Raw Materials

Zinc occurs most frequently in nature in the form of zinc sulphide, but it also occurs as zinc oxide compounds. Mineralogically, zinc ores are divided into sulphidic and oxidic types. Sulphide ores usually contain zinc in the form of sphalerite (ZnFeS) in concentrations up to 67%, hemimophite ($Zn_4SIO_7(OH)_2.H_2O$) in concentrations up to 54% , zinc calamine or smithsonite ($ZnCO_3$) in concentrations up to 52%, willemite (Zn_2SIO_4) in concentrations up to 59% (Woodcock, 1980).

5.3 The Basic Methods of Recovering Zinc from Raw Materials

Two basic methods for recovering zinc from zinc concentrates are recognised: pyrometallic and hydrometallic. The pyrometallic method is most frequently used to oxidise zinc sulphide (ZnS) in order to produce zinc oxide (ZnO). The hydrometallic method is used to produce zinc metal from the zinc oxide or directly from zinc sulphide.

Despite the low temperatures needed for melting and boiling zinc concentrates, zinc sulphide and zinc oxide have high melting and boiling points. According to Zaitsev and Margulis (1985: 112-113), the pyrometallic and hydrometallic methods for reducing zinc concentrate to metallic zinc differ substantially. The pyrometallic method of zinc production begins with the roasting of zinc concentrate to produce a product in the form of hard 'porous lumps'. The product is then sintered at temperatures of 1300–1400°C to produce zinc vapour which is subsequently distilled and condensed to arrive at metallic zinc.

In contrast, the hydrometallic method involves roasting zinc concentrate at temperatures of 900-1000°C to produce a powdered clinker. This material is then leached in an acid solution before undergoing electrolysis to produce the zinc metal. The hydrometallic method has superceeded the pyrometallic method because its allows for the processing of low-grade complex zinc ores, enables the use of convenient forms of energy, is energy efficient and produces high quality metallic zinc while enabling effective pollution prevention (Zaitsev and Margulis, 1985; EPA, 1995).

Although commercial zinc production began, and continued for a considerable period, using the pyrometallic method which involved employing blast furnaces, horizontal and vertical retort processes, the production of metallic zinc by this method has become less popular in the last few decades (Habashi, 1997). Table 5.1 shows that the pyrometallurgical process in general, and the two principle methods, horizontal and vertical retorting, have been in steady decline since 1960. Conversely, the electrolytic (electrowinning) production of zinc has been steadily increasing during the same period.

Table 5.1. Production of zinc by different methods

Method and its forms	First use	Fraction of method in total zinc production, % by year				
		1960	1970	1975	1980	1982
Pyrometallurgic, total:		55	44	26	21	20
Horizontal retort	1800	34.5	15	3	7	6
Vertical retort	1930	11	10	7	7	6
Electric furnace	1936	7.5	6.5	6	4	4
Shaft furnace	1950	2	12.5	10	10	10
Hydrometallurgical:						
electrolytic	1916	49	57	70	79	-

(Source: Monhemius, 1980; Saitzev and Margulis, 1985)

Due to the difficulty of obtaining data on these methods of zinc production in recent years, these data are not presented in this paper.

Approximately 80% of the total world zinc production comes from the electrolytic process. Thus, the pyrometallurgic processes for zinc production will not be examined in this chapter.

5.4 Modern Zinc Production – the Electrolytic Process

Table 5.1 shows that in 1980 the electrolytic method (a form of hydrometallurgy) of zinc production was the most popular method for extracting metallic zinc from zinc ores. Furthermore, at that time almost 80% of global zinc production was produced by this method, and although current figures for total global zinc production and the refining processes used are unavailable, there is no reason to believe that this steady increase in the use of the electrolytic process has not continued.

Electrolytic zinc refining generally consists of four main stages: the roasting of zinc concentrate to produce calcine, leaching, and the purification and electrolysis of the leachate. The two principal processes, however, are considered to be the roasting of the zinc concentrate and the leaching of the calcine. The purification and electrolytic phases of the process, because of their

limited relevance to environmental management issues, are excluded from this discussion.

5.4.1 Roasting of zinc concentrate

The roasting of zinc concentrate is common to both pyrometallic and hydrometallic (electrolytic) zinc refining. Roasting is a high temperature process that is used to remove or eliminate sulphur and to convert zinc sulphide to an impure zinc oxide called calcine (Dames and Moore, 1995a; Zinc Corporation of South Africa Limited, 1999) and to render the calcine soluble in a plant solution to increase its capacity for purification by electrolysis (PMEZ, 1999). The sulphur dioxide gas produced during roasting is cleaned, dried and oxidised to produce sulphur trioxide which is then reacted with water to produce sulphuric acid (Zinc Corporation of South Africa Limited, 1999).

The technologies for roasting zinc concentrates are relatively similar. The differences involve the methods for preparing the raw material for roasting, the construction of the fluid bed furnace, the transport and handling of the calcine to the leaching process, the roasting temperature, and the methods for using the heat from the fluid bed furnaces (Zaitsev and Margulis, 1985: 125). The roasting of the zinc concentrate can be carried out in suspension, fluidised-bed or multiple–hearth.

5.4.1.1 Suspension Roasting

Suspension or flash roasting is a process used to remove sulphur and convert zinc to calcine by allowing concentrates to fall through a heated oxidising atmosphere or by blowing them into a combustion chamber (Corwin et al. 1982). The roaster usually consists of a refractory-lined cylindrical shell with a large combustion space at the top, and two to four hearths in the lower portion (EPA, 1995: 43). Suspension roasters are normally unpressurised and operated at an average temperature of 980°C (Corwin et al., 1982; EPA, 1995: 43).

5.4.1.2 Fluidised Bed Roasting

The fluidised-bed roasting of zinc concentrate is the new method for removing sulphur and converting zinc to calcine. It requires that the sulphide concentrates be finely ground before suspension and oxidation on a feed stock bed supported on an air column. Fluidised bed roasters normally operate at an average temperature 980°C under a pressure slightly lower than atmospheric (EPA, 1995: 44). The principle of this process is to slowly move the gas upward through a bed of small solid particles ranging from 0.02 – 2mm in diameter. This low rate of flow allows gas to permeate the bed without moving the particles. When the velocity of gas is increased the particles begin to move within the bed and resemble a high viscosity liquid. This stage initiates the onset of fluidisation (Gilchrist, 1986). This type of roasting offers several advantages including low manning, lower maintenance costs, higher operation efficiency (PMEZ, 1999; Dames and Moore, 1995a) and a high capacity for sulphur removal (EPA, 1995: 44). This process is widely used in many countries such as Canada, Russia and the US. In Tasmania a similar method of roasting is used at Pasminco Metals-EZ.

5.4.2 Leaching

The main purpose for leaching is to recover iron and other materials from calcine.. Primarily, the zinc ferrites ($ZnFe_2O_4$) that form during the roasting process are dissolved in a solution of sulphuric acid to form a zinc sulphate solution (Dames and Moore, 1995a; Monhemius, 1980; Zinc Corporation of South Africa Limited, 1999). Leaching of the calcine is a closed-circuit process that varies according to temperature and concentration conditions: neutral, hot acid and strong acid (Zaitsev and Margulis, 1985: 133). The calcine may be leached in a single or double-step leaching procedure. In single-step leaching calcine is contacted only once with a solution of sulphuric acid. According to Corwin et al. (1982), single-step leaching is not widely used, as the loss of sulphuric acid is excessive and the recovery of zinc poor. Double-step leaching is more common. In this method, the calcine is dissolved in a neutral or slightly acidic solution to remove the sulphate. Calcine is then leached a second time in a stronger acid solution (EPA, 1995: 44). The leaching process commonly

operates under atmospheric pressure at a temperature of 50°C. However, in the hot acid leaching process the temperature may reach up to 90°C at a pressure of up to 2.5 kg/cm^2 (Corwin et al., 1982). The leaching methods for removing iron and other minerals differ from plant to plant. The most common methods used are: Jarosite, Goethite, Hematite and Acid Pressure Leaching.

5.4.2.1 Iron Removal by Jarosite Process

The precipitation of iron as ferric sulphate from acidic sulphate solutions is known as jarosite. Jarosite's composition is $MFe_3(SO_4)_2(OH)_6$, where M represents a monovalent group of metal such as Na^+, K^+, Ag^+ (PMEZ, 1991). According to Habashi (1997), the precipitation of jarosite begins at a pH< 1 and is completed at pH of 1.5 with the addition of sodium or ammonium ions at a temperature of 95°C (low acid concentration–5-10g H_2SO_4/L) or 180°C (high acid concentration – 60-90g/L). The yield from this process is about 96%-98%. The reaction of iron precipitation to form jarosite is:

$$3Fe_2(SO_4)_3 + M_2SO_4 + 12H_2O \rightarrow 2MFe_3(SO_4)_2(OH)_6 + 6H_2SO_4 \quad (1).$$

Source: PMEZ (1999).

A flow diagram is shown in Figure 5.1.

The jarosite process offers some advantages that include simple and low cost technolgy. The process, however, involves the production of a large volume of residue, low concentrations of zinc (4%-6%) and iron (approximately 37%), and the jarosite precipitates do not effectively absorb the harmful impurities. Thus the residues produced by this process must be disposed in a secure place.

5.4.2.2 Iron Removal by Goethite Process

Goethite is a new leaching process that has been developed for leaching zinc sulphide concentrates at atmospheric pressure using air or oxygen plus nitrogen dioxide in dissolved or gaseous form (PMEZ, 1999). A similar process (paragoethite) has also been developed and is being use at Pasminco–EZ. A flow diagram of this process is shown in Figure 5.2. Goethite is an alternative

method for precipitating iron in crystall form as ferric oxide. Goethite is the process that was commercially developed and used by the Societe de La Ville Montagne. The basic principal of this process is that ferrite is reduced to ferrous iron using sulphides or unroasted zinc sulphide (as the reduction agents) whilst maintaining a pH of 3-4 and a temperature of 90-95°C (Monhamius, 1980).

Figure 5.1. Flow Diagram of the Jarosite Process With Pre-Neutralisation

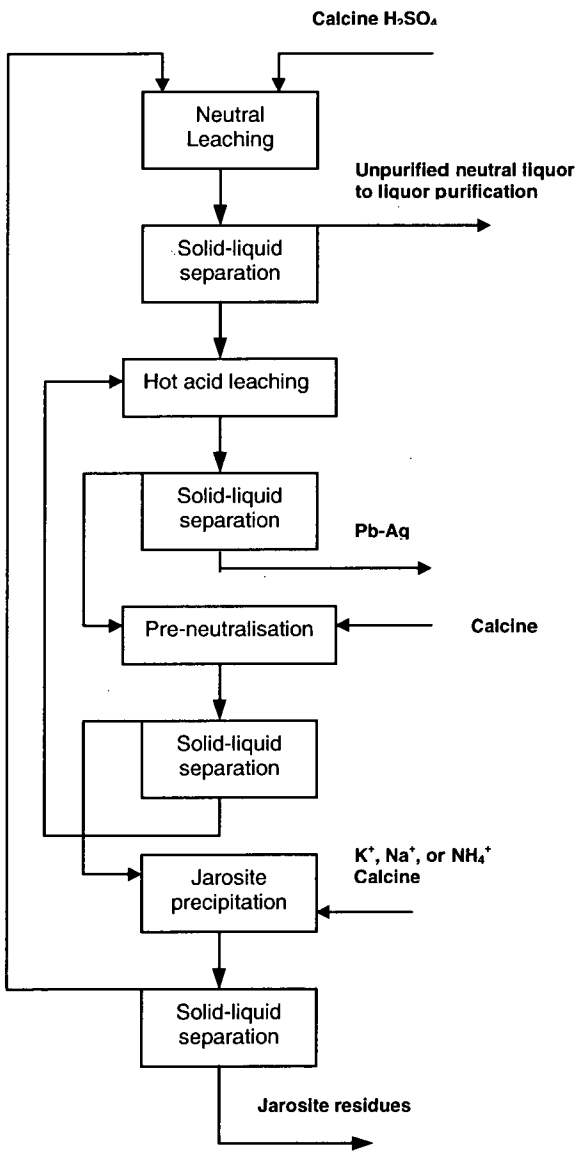
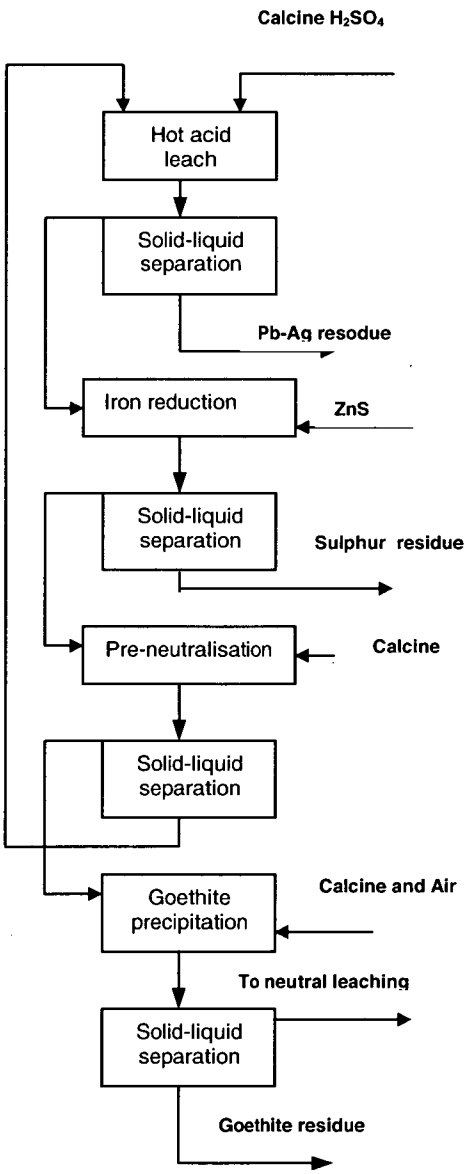


Figure 5.2. Flow Diagram of the Goethite Process



(Sources Habashi, 1997).

When the ferrite iron is reduced to a ferrous state the iron is then re-oxidised by using air or oxygen. As a result, ferric iron (FeOOH) is formed and precipitated in the solution. The reaction is:

$$Fe_2(SO_4)_3 + ZnS \rightarrow 2FeSO_4 + ZnSO_4 + S \qquad (2).$$

$$2\ FeSO_4 + O + 3H_2O \rightarrow 2FeOOH + 2H_2SO_4 \qquad (3).$$

(Source: Habashi, 1997)

The advantages of this process are that it has a greater ability to recover iron, while the amount of residue to be disposed of is considerably less than that produced by the jarosite process. Compared with the traditional polymetallic smelter, this process also provides an increased ability to treat mixed concentrates, while the zinc yield from this process is comparable to the jarosite process (Habashi, 1997). It is, however, hard to control the precipitation conditions such as pH and moisture contents (Dames and Moore, 1995a). Furthermore, the recovery of the undissolved zinc from the calcine added to control the pH in the acid sulphuric liquor is also challenging. This process is used world wide for extracting iron from calcine and the process is used at PMEZ.

A number of processes are being operated or are under development as alternative ways for disposing of goethite residue. For example, in the Italian zinc hydrometallurgical plant in Porto Vesme (Sardinia) the goethite residues are treated in a Waelz Kiln. The goethite residue is blended with other materials such as oxidised ores, residues and limestone, and burned in a coal fired kiln at a temperature of 1100°C for 6 hours. The material from the kiln is then mixed with water to produce a powdered and glassy material which can be safely stockpiled or disposed (Pelino et al., 1995).

5.4.2.3 Iron Removal by the Hematite Process

The first hematite plant began production at Ruhr-Zink in Datteln in 1979. In hydrometallurgy, the hematite process is a new process for recovering zinc and removing iron from solution. The hematite process was developed by the Akita zinc company's plant in Japan. In this process, the leach residue is

repulped in electrolyte and then passed through autoclaves containing sulphur dioxide at temperatures of 95–100°C and pressures of 0.2 MPa. The solution is then treated with hydrogen sulphide to remove excess sulphur dioxide (SO_2), copper and lead from the solution (Monhemius, 1980). The solution is then treated with limestone to maintain a pH of 2 which is required to produce gypsum and to precipitate some of the iron and other impurities (Monhemius, 1980). In the final stage, the iron is oxidised and precipitated as hematite (Fe_2O_3) by oxidation with oxygen at 200°C and a pressure of 2 MPa (Monhemius, 1980). The differences in the chemical reactions and the quantities of residues from these processes are outlined below:

$6FeSO_4 + 1/2\ O_2 + 11\ H_2O \rightarrow \quad 2H_3OFe_3(SO4)2(OH)6H_2SO_6$ (jarosite)

$2FeSO_4 + 1/2O_2 + 3H_2O \quad \rightarrow \quad 2FeO(OH) + 2H_2SO_4$ (goethite)

$2FeSO_4 + 1/2O_2 + 2H_2O \quad \rightarrow \quad Fe_2O_3 + 2H_2SO_4$ (hematite)

Table 5.2 presents residue quantities of jarosite, goethite and hematite iron removal processes.

Table 5.2 Residue Quantities

Element	Composition of residue (%)		Quantity of Residue for 100,000 tonnes per annual Zinc Plant
	Theory	Actual	
Ammonium-Jarosite–$(NH_4)\ Fe_3(SO_4)_2(OH)_6$ –M = 490			96,000 with 50% H_2O
Fe	37	30	
S	13	10	
Zn	4-6	4	
Goethite – FeOOH – M = 89			70,000 with 50% H_2O
Fe	63	41	
S	-	1	
Zn	-	8	
Hematite – Fe_2O_3 – M = 160			27,000 with 10% H_2O
Fe	70	59	
S	-	1.5	
Zn	-	1.0	

(Source: Ropenack, 1990: 647).

According to Habashi (1997) and Ropenack (1990), hematite offers a more ecologically acceptable and saleable product compared to goethite or jarosite which produces a worthless waste which must be dumped. The process also makes possible an almost 100% recovery of zinc, lead, copper and silver. However, the process involves, however, higher capital and operating costs.

5.4.2.4 Iron Removal by Acid Pressure Leaching

This process was developed by Sheritt Gordon Mines in Canada in the early 1950s. Following this development a pilot plant was built at Fort Saskatchewan in 1977 by Sheritt and Cominco, and was fully operational by 1981. In this process zinc sulphide concentrates are directly oxidised under pressure to produce zinc sulphate in solution. The process consists of oxidising aqueous zinc sulphide concentrate in acidic solution (H_2SO_4) at 150°C in an oxygen atmosphere at 700 KPa (Molison, 1990). The basic chemical reaction is:

$$ZnS + ½\ O_2 + H_2SO_4 \rightarrow ZnSO_4 + H_2O + S°$$

(Source: Zaitsev and Margulis, 1985)

According to Collins et al. (1990) pressure leaching offers an alternative for roasting in the expansion plans of existing zinc plants or in the design of new grass roots facilities. The process can also be modified to meet the special requirements of variable feed grades and by-product recovery. Sulphur produced by the process is converted into the sulphuric acid required for the production. In addition to elemental sulphur, the pressure leach residues can be treated for the recovery of lead and silver values. Furthermore, the process also offers economic advantages over the traditional roast-leach process due to its lower cost of capital investment. At present, two plants are operating using this technology: the Kidd Creek Zinc plant at Timmins, Ontario; and the Hudson Bay Mining and Smelting Plant in Flin Flon, Manitoba (Habashi, 1999).

5.5 Environmental Parameters from Zinc Refinery

Cadmium

Cadmium is a toxic substance to both aquatic systems and human health. Cadmium is found naturally in crystal rock and soils, while

anthropogenic sources are non-ferrous smelting, battery plants, electroplating, textile printing, mine drainage and metallurgical alloying. In the case of the Derwent Estuary, Pasminco-EZ represents the main anthropogenic source of this metal. Cadmium occurs in the aquatic environment in a number of forms such as free ions, inorganic, organic complexes and colloid/particulate associated cadmium. ANZECC (1992) recommends that the concentrations of cadmium in fresh and marine waters should not exceed 0.2-2 µg/L and 2 µg/L respectively.

Zinc

Zinc is an essential element for plants, animals and humans. Exceeding concentrations of 50µg/L in the aquatic environment, however, can create negative effects on aquatic life. ANZECC (1992) recommends that zinc concentrations in fresh waters should not exceed 5-50 µg/L in fresh water and in 50 µg/L in marine waters.

Zinc is an abundant element in most rocks and soils. Anthropogenic sources of this element mainly come from manufacturing activities such as steel works with galvalnising manufacturing, zinc extraction facilities, ground wood pulp and newsprint production plants (Patterson, 1985). Patterson notes that the concentrations of zinc in zinc refinery effluent (in combined effluent and acid plant) range from 11-243 mg/L and 25-15 000 mg/L respectively.

Lead

Lead is another serious environmental pollutant. It is widely distributed in rock and soils in the range of 12-20 ppm (Settle and Patterson, 1980). Lead is generally present in relatively low concentrations in natural water.

This metal has a number of physio-chemical forms such as free metal ions (Pb^{2+}), inorganic complexes (such as $PbHCO^{3+}$, $PbCO^{3+}$), organic complexes, and those forms associated with organic and inorganic colloids/ particulates (Florence and Bateley, 1980: 231). ANZECC (1992) contends that the forms of lead present in fresh water are $PbCO_3$ and lead organic complexes, while lead carbonate is found mainly in marine waters.

High concentrations of lead can have negative affects on marine life in receiving waters. ANZECC (1992) recommends that the concentrations of lead in fresh and marine waters should not exceed 1-5 µg/L and 5 µg/L respectively.

Copper

Copper is a common pollutant in natural waters. Although it presents only a low toxicity to humans it can cause acute toxicity to aquatic organisms at very low concentrations (ANZECC, 1992). ANZECC (1992) further notes that copper is commonly found in the free ion copper state Cu^{+2} in natural waters, and it is believed that in this state it is the most toxic to aquatic life.

Copper is derived from both natural and anthropogenic sources. The examples of anthropogenic sources include metallurgical processes and mining operations. Pulp, paper and paper-board mills and fertilizer plants are also substantial sources of copper (Patterson, 1985).

According to Hanslow (1994), copper exhibits a marked tendency to form complexes with a wide range of inorganic (hydroxides, carbonate, bicarbonates) and organic ligands in aerobic waters.

5.6 Pollution Reduction Technology

The following section presents an evaluation of the best available technology for treating industrial wastewaters containing heavy metals. These treatments include chemical precipitation and chemical exchange.

5.6.1 Chemical Precipitation

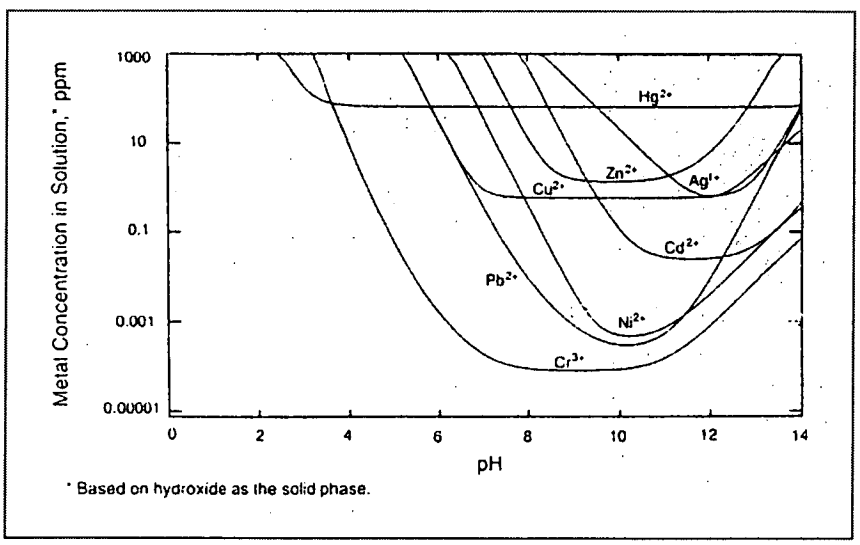
The precipitation of heavy metals from wastewater involves the addition of chemicals to change the physical state of the dissolved or suspended metals, and to facilitate their removal through sedimentation (Krishnan et al., 1992; Pfafflin and Ziegler, 1992). Chemicals used for this purpose include caustic soda, lime, sodium sulphide, soda ash and ferrous sulphide. The sedimentation of heavy metals from wastewater is usually achieved by adding coagulant/flocculants (lime, alum and synthetic polyelectrolytes) to agglomorate the metal salt particles into the larger forms that will settle out of solution

(European Commisssion, 1996). Two common methods of chemical precipitation widely used to remove heavy metals such as cadmium, zinc, copper, lead and mercury are hydroxide precipitation and sulphide precipitation.

5.6.1.1 Hydroxide Precipitation

Hydroxide precipitation is the most widely used precipitation method to recover inorganic matter and metals from industrial wastewater. The precipitation of heavy metals by this method is usually achieved by adjusting the wastewater pH to alkaline, causing the soluble metal ions to form insoluble metal hydroxide (Cheremisinoff, 1989). The pH adjustment can be achieved by adding limestone (calcium carbonate), caustic soda (sodium hydroxide) or lime (calcium hydroxide). The effectiveness of heavy metal removal by this method depends on the addition of chemical reagents and pH adjustments to the wastewater (Figure 5.3). The minimum removal of soluble heavy metals from wastewater is shown in the Table 5.3. Heavy metal concentrations in the effluent can be further reduced by sand filtration following sedimentation. Compared to other precipitation methods, hydroxide precipitation is the most economic method for removing dissolved heavy metals from wastewater (Cheremisinoff, 1989).

Figure 5.3 Precipitation of heavy metal ions in equivalent of pH adjustment.



(Source: Smith, Means and Barth, 1995)

5.6.1.2 Sulphide Precipitation

Sulphide precipitation is an alternative precipitative process to hydroxide precipitation, or it can be used as a polishing step following hydroxide precipitation. The sulphide precipitation process is the most widely used for removing inorganics, especially mercury (Cheremisinoff, 1989). According to Patterson (1985), sulphide precipitation appears to be the standard method for mercury removal in many countries, including the USA.

The average metal concentrations in wastewater discharges from hydroxide and sulphide precipitation processes are shown in Table 5.3.

Table 5.3 Hydroxide and sulphide precipitation metal removal effectiveness

Metal	Inlet Concentration (mg/L)	Residual Concentration (mg/L)	Inlet Concentration (mg/L)	Residual Concentration (mg/L)
Cadmium	3.10	0.21	440-1000	0.08
Zinc	16.1	0.02-0.23	3.2	0.09
Copper	204-385	0.2-2.3	50-115	0.5
Lead	0.5-25	0.03-0.1	-	-
Mercury	-	-	6.0	0.05

(Source: Krishnan et al., 1992).

5.6.1.3 Carbonate Precipitation

Carbonate precipitation is also a proven technology for removing heavy metals (cadmium, lead and zinc) from industrial wastewater. Removing these metals can be achieved either by direct precipitation or by converting hydroxide into carbonate using carbon dioxide or chemical reagents such as soda ash (sodium carbonate) or calcium carbonate (limestone) to directly precipitate the heavy metals from the wastewater (Noyes, 1991). While the carbonate precipitation method is widely used due to its superior handling characteristics, for example, its low levels of sludge generation, good flow and absence of arching in the feeder, the process has its drawbacks. These include the slow

reaction time (typically a minimum of 45 minutes retention) and a low solubility (about 20% by weight) (Krishnan et al., 1992).

Chemical precipitation is a proven technology for treating a wide range of industrial wastewater, including wastewater from non-ferrous metal production. This method can result in very low concentrations of metal contaminants in the treated water while the treatment system is simple, has a low capital-cost, and the equipment is commercially available (Smith et al., 1995).

A summary of the most common technologies for metal treatment is given in Table 5.4.

Table 5.4 Metals Removal Processes

Parameter	Treatment Processes
Cadmium	• hydroxide precipitation with lime or caustic
Zinc	• hydroxide precipitation with lime or caustic • sulphide precipitation with hydrogen sulphide or sodium sulphide
Copper	• hydroxide precipitation with lime or caustic • sulphide precipitation • co-precipitation with alum or ferrous sulphate
Lead	• hydroxide precipitation with lime or caustic, and alum (inorganic) • ion exchange (organic)
Mercury	• sulphide precipitation

(Source: Cheremisinoff, 1989; Patterson, 1985).

Other chemical precipitation processes also exist. These include carbonate precipitation, sodium borohydride precipitation and zinc cementation.

Sodium borohydride ($NaBH_4$) is a strong reducing reagent developed in the 1960s capable of removing metals to lower concentrations than other conventional treatment methods. It results in low sludge volumes compared with conventional hydroxide precipitation methods (Cushie, 1985), but this method is not widely used due to the high cost of the reagent (Krishnan et al., 1992). The

zinc cementation treatment method uses zinc powder as a reagent to precipitate elements that are more electro-negative than zinc (chrome or copper) (Krishnan et al., 1992). These authors further note that although this method has been shown to be effective in precipitating lead and cadmium from wastewater, and treating mercury in sludge, it is unsuitable for treating heavy metals in wastewater.

5.6.2 Ion Exchange Treatment Process

The ion exchange treatment process involves the use of a synthetic resin to exchange a contaminant ion with high ion exchange selectivity for an ion with a lower selectivity (Neglia, 1989). According to Krishnan et al. (1992), the ion exchange treatment process is applicable not only to wastewater where metals are present as soluble 'ionic species', but it is also applicable to non-metallic anions such as sulphate, nitrate and cyanide and to water soluble ionic organic compounds and amines.

The ion exchange treatment process is a fully developed and commercially available technology. According to Krishnan et al. (1992) and Patterson (1985), ion exchange is a proven technology for removing soluble metals such as cadmium, copper, lead, mercury and zinc. Table 5.5 summarises data on the effectiveness of ion exchange in removing soluble metal ions in commercial, pilot plant and laboratory operations.

Table 5.5 Ion Exchange Heavy Metal Removal Effectiveness

Metal	Treatment Process Types	Influent Concentration (mg/L)	Effluent Concentration (mg/L)
Lead	Laboratory	126.7-144.8	0.020-0.053
Copper	Commercial	45.0	Not detected
Mercury	Commercial	5-25	0.001
Zinc	Pilot-plant	6.0	0.4
Arsenic	Laboratory	2.3	0.52

(Sources: Krishnan et al., 1992; Patterson, 1985)

Ion exchange processes have been effective and widely used due to their low operating, maintenance and equipment costs. These processes are not, however, without disadvantages. These include the regeneration of ion exchange resins to remove metals collected from wastewater, and the pretreatment of the wastewater which is necessary to reduce high concentrations of suspended solids or organic substances.

Other technology for removing heavy metals also exists, for example, reverse osmosis, ultrafiltration and electrodialysis. These treatment processes are normally only suitable for small scale effluent treatments such as the effluent from electroplating, photographic processing or battery plant.

5.7 Conclusion

The high, anti-corrosive properties of metallic zinc result in it being widely used for galvanising steel and iron. Zinc is a natural element occurring mainly as a sulphide (sphalelite – ZnFeS, hemimophite – $Zn_4SIO_7(OH)_2.H_2O$, calamine – $ZnCO_3$, Willemite – Zn_2SIO_4) and to a lesser extent, as oxide compounds.

Pyrometallurgy and hydrometallurgy are the two recognised methods for recovering metallic zinc from zinc concentrate. The pyrometallurgy method comprises various alternative processes such as the use of a blast furnace, shaft furnace, horizontal or vertical retorting technology. These methods have, however, become obsolete in the last few decades.

In an effort to achieve better environmental performance and greater economic competitiveness various methods have recently been developed for recovering zinc. The electrolytic process for zinc extraction (a form of hydrometallurgy) is now recognised as a leading development in this metallurgical area.

The electrolytic process consists of four main steps: roasting the zinc concentrate, leaching of the calcine, purification of the calcine and electrolysis. The roasting of the calcine is commonly practiced in both pyrometallurgy and hydrometallurgy. In hydrometallurgy, zinc concentrate is roasted at high

temperatures to remove the sulphur contained in the zinc concentrate (zinc sulphide) to produce sulphuric acid. In the electrolytic process, roasting of calcine can be achieved by suspension roasting or fluidised bed roasting.

The leaching of the calcine is the most significant step in the zinc extraction process and is normally used to recover the iron and other materials contained in the calcine. Such leaching may be carried out in aqueous sulphuric acid in single or double-stage processes. The single stage process is not widely practiced due to poor recovery of zinc and the significant loss of sulphuric acid solution. Double stage leaching is more widely practiced. In double-stage leaching the calcine is first dissolved in a neutral or slightly acidic solution before being subjected to a stronger concentration of sulphuric acid at higher temperatures (hot acid leaching).

The leaching process involves the precipitation of iron, a process which varies from plant to plant. However, the most common precipitative methods are jarosite, goethite (paragoethite), hematite and acid pressure leaching.

The precipitation of iron as crystaline jarosite (ferric sulphates) from aqueous solution has been widely practiced in the past few decades because of its low cost and ease of handling. This process involves the production of large volumes of residue, the residue with low concentrations of zinc and iron (approximately 4% and 30% respectively) and needs to be disposed of safely.

The goethite process is a relatively new development for leaching zinc concentrate (zinc sulphide). Compared to the jarosite process, the goethite process (paragoethite) has a superior ability for recovering iron and zinc, about 63% and 6%-8 % respectively. The residue volumes produced by this process are also considerably lower than those produced by the jarosite process.

The hematite process is one of the most recent technologies for recovering zinc and iron. Compared to the two previous methods this method is more ecologically appropriate, while also resulting in a more saleable product (residue). The process also makes it possible to recover 100% of the metals

such as zinc, lead, copper and silver. This process, however, involves higher investment capital as well as operating costs.

Acid pressure leaching is also an alternative method for recovering zinc and iron materials. According to Habashi (1999), acid pressure leaching is recognised as the best available technology for zinc production. Acid pressure leaching not only offers an alternative for leaching calcine, but provides cost-effective means for expanding existing plants or modifying or designing new facilities. The process can also be modified to meet the requirements of low grade by-product raw materials and low capital investment and operation costs. The residues produced by this process are also saleable and may be treated to recover other materials such as lead and silver.

Pollution loads from the zinc refining industry vary depending on the technology employed. However, pollution loads from this industry are generally characterised by high concentrations of heavy metals including cadmium, copper, zinc, lead and mercury.

To achieve better environmental performance the pollution load of plant effluent must be reduced before being discharged into the receiving environment. External measures can be effective in reducing pollution loads. Such measures require reducing the levels of toxic heavy metals or toxic waste materials released from the plants. External treatments involve chemical (hydroxide precipitation, sulphide precipitation, carbonate precipitation) and ion exchange treatment.

Chemical precipitation (hydroxide precipitation, sulphide precipitation and carbonate precipitation) is a proven and widely practiced technology for removing toxic heavy metals due to its simplicity, low capital cost and commercial availability. Low concentrations of heavy metals in the treated effluents can also be achieved by this method. Hydroxide precipitation is the most widely used precipitative method for recovering inorganic materials and metals such as chrome, lead, nickel and cadmium from industrial wastewater. Compared to other chemical precipitative processes, hydroxide precipitation

offers the most economic method for removing dissolved heavy metals. Sulphide precipitation is an alternative method to hydroxide precipitation. This method is especially practical and widely used for removing inorganic mercury. Carbonate precipitation is also a proven technology for effectively removing heavy metals. The use of chemical reagents such as soda ash (sodium carbonate) or calcium carbonate (lime stone) for directly precipitating heavy metals from wastewater, and the superior handling characteristics of there reagents (low sludge generation, good flow and no arching in feeder) have made this process widely used and practiced.

Ion exchange treatment is also a fully developed and commercially available technology. The ion exchange treatment process is widely used for removing heavy metals, and in well designed and maintained plants excellent heavy metal removal may be achieved (up to 0.02 mg/L of lead, 0.01 mg/L of mercury and 0.4 mg/L of zinc).

In this chapter various technologies of zinc production including their characteristic emissions and treatments have been discussed and evaluated. The following chapter will introduce the case study of the zinc refinery facility investigated for this thesis. The use of this case study will also further investigate issues raised in the in the zinc refinery industry in relation to best available technology and best practice environmental management.

Chapter 6
Pasminco Electrolytic Zinc Company (PMEZ)

6.1 Background

The Pasminco-Electrolytic Zinc Company (PMEZ) is situated at Risdon, on the western shore of the Derwent Estuary. The refinery was established in 1917 in response to a world zinc shortage, but did not begin commercial operations until 1921 (Alexander, 1992). The principal reasons for establishing the zinc smelter in Hobart were the availability the considerable amount of cheap electricity required for production, the deep-water port facilities and the availability of a resident workforce.

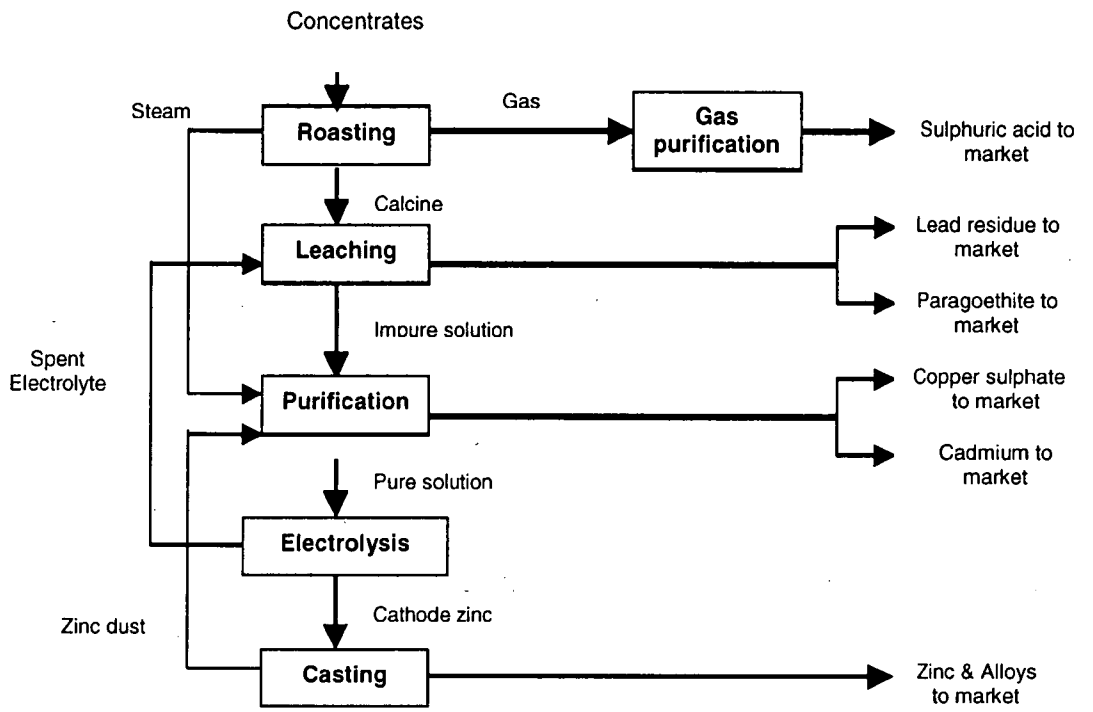
Currently, the zinc plant purchases zinc concentrates from Broken Hill in New South Wales, while part of its needs are supplied by its own mines at Rosebery and Aberfoyle Resources Ltd's Hellyer Mine on the west coast of Tasmania.

Technological processes at PMEZ involve roasting, leaching, purification, electrolysis and casting (PMEZ, 1999). The electrolytic zinc process is summarised as follows:

- zinc concentrate (zinc sulphide) is roasted in two fluid bed roasters to produce calcine (zinc oxide), plus sulphur dioxide gas. The sulphur dioixde is recovered in the form of sulphuric acid.
- the calcine is leached in an acidic solution to dissolve the zinc to produce purified zinc sulphate.
- purification of the impure solution from leaching takes place in primary and secondary stages to remove cadmium, nickel and cobalt.
- the purified solution is then electrolysed in the cell room to form zinc metal on the cathodes.
- the zinc cathode sheets are melted in electric induction furnaces and cast as zinc blocks.

Figure 6.1. shows a general schematic of the electrolytic zinc process.

Figure 6.1. General flow sheet of the electrolytic zinc process



(Source: PMEZ, 1999)

PMEZ is one of the world's largest producers of zinc metals and alloys, having an annual production of approximately 215 000 tonnes. Other products include cadmium, lead residue, sulphuric acid and copper sulphate. Annual production of these products are about 360, 27 000, 391 000 and 3 100 tonnes respectively (PMEZ, 1999).

6.2 Brief description of zinc production at the Risdon zinc refinery

The following description of the zinc refining process has been summarised from Pasminco's reports 'Pasminco Smelter Process Outline' (PMEZ, 1998) and 'Pasminco Hobart Smelter Process Description' (PMEZ, 1999).

6.2.1 Roasting

Prior to 1940 the roasting of zinc concentrate was carried out in two stages: the first stage was carried out on the mainland, followed by the re-

roasting of the concentrate at the Hobart smelter. Roasting is currently carried out in two fluid bed roasting furnaces (No. 5 and No. 6) that were commissioned in 1969 and 1975, and which have a capacity of 420 tonnes/day and 930 tonnes/day respectively. During the roasting operation, zinc concentrate containing 8% moisture is recovered from the roaster feed bins and passed through a rotary feed table to high speed slinger feeders which inject the concentrate into the furnaces at high velocity. Under operating conditions the temperature in the fluid bed ranges between 900°C and 930°C. During roasting the zinc sulphide is converted into zinc oxide and sulphur dioxide gas. Iron concentrate is also oxidised and forms zinc ferrite. The furnace gases produced during roasting pass through the No.5 and No.6 sulphuric acid plants.

6.2.2 Leaching

The purpose of the leaching stage is to dissolve the zinc from the calcine. At PMEZ, the calcine leaching process comprises five stages: Strong Acid Leaching (SAL), Hot Acid Leaching (HAL), Pre-neutralisation (PN), Paragoethite (PG), and Neutral Leaching (NL). Zinc calcine consists of zinc oxide and zinc ferrite together with small quantities of zinc sulphate and zinc sulphide. Zinc oxide is largely dissolved in a weak acid in the PN, PG and NL stages, whereas zinc ferrite, zinc sulphate and zinc sulphide require the stronger and hotter conditions present in the HAL and SAL stages. A general flow sheet of the leaching process is shown in Figure 6.2.

6.2.2.1 Strong Acid Leach (SAL)

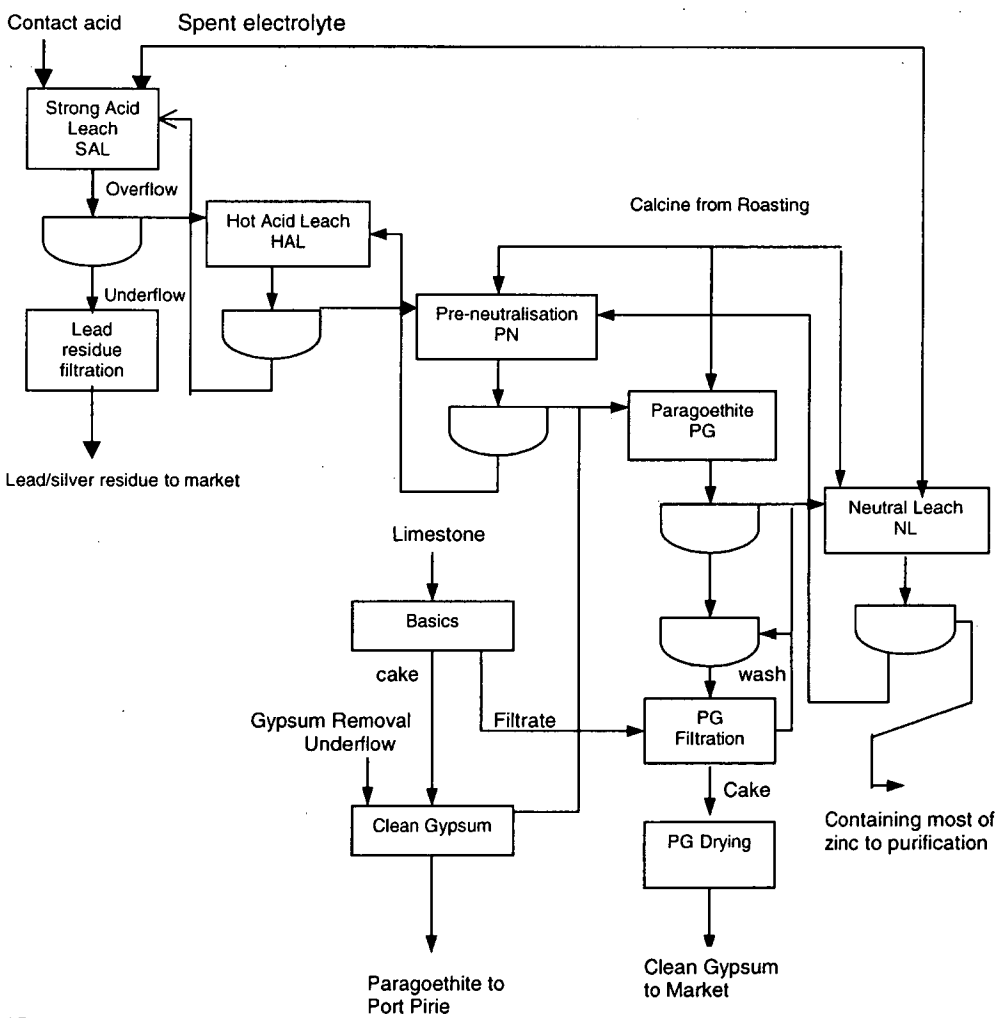
The strong acid leach is used to leach the already substantially leached zinc ferrite from the HAL stage. Strong acid leach operates at a temperature of 90°C, with a concentration of 120 g/L of sulphuric acid and a retention time of approximately 2 hours. About 60% of the total spent electrolyte flowing from the electrolysis stage enters this stage, while the remaining 40% enters the NL stage. In this SAL stage the remaining zinc ferrite and any potassium or other form of jarosite which is precipitated in the earlier stage is completely dissolve. The remaining undissolved solids are filtered off to recover the lead residue and

the silver. Approximately 70 tonnes/day of lead residue, 31% of lead, and 900 g/tonne of silver is recovered.

6.2.2.2 Hot Acid Leach

The hot leaching stage is where zinc ferrite residues from the PN and SAL stages overflow. The undissolved zinc sulphide, which is present in the calcine, is dissolved at this stage. The hot acid leach operates at a temperature of 85°C, with an acidity in the range of 55-65 g/L of sulphuric acid and a retention time of about four hours. The overflow from the HAL stage is then passed to the PN stage.

Figure 6.2 Leaching Flow sheet



(Source: PMEZ, 1999)

6.2.2.3 Pre-neutralisation

The main purpose of pre-neutralisation is to reduce the acidity of the HAL overflow before it enters the PG stage, and to re-leach the residues from the NL stage. During this process the overflow from the HAL stage is reduced to about 5g/L sulphuric acid to control acidity and minimise the ferritic residue loss in paragoethite. The PN underflow pulp is then pumped back to the HAL stage for repulping and rethickening in the HAL liquor. The retention time in this stage is short so as to avoid the formation of jarosite.

6.2.2.3.1 Paragoethite Precipitation

The solution from the PN stage contains approximately 15-20 g/L of ferric iron which is then precipitated as paragoethite or iron 'oxy-hydroxide'. Other small quantities of potassium, sodium and hydronium jarosite also form during this stage. During the process, calcine is added as a neutralising agent to reduce the acidity, while the ferritic residue from the calcine remains in the paragoethite. The slurry is then settled in thickeners and the solids pumped to the PG filtration plant. The overflow liquor is passed through to the NL stage.

6.2.2.4 Neutral Leaching

The neutral leaching stage is used to remove the remaining iron from the PG overflow, and to achieve a preliminary extraction of zinc oxide from the slurry that is formed from the roasting of the calcine. At this stage, several oxidation tanks are deployed to oxidise the ferrous iron to ferric iron which precipitates as ferric hydroxide. Several impurities such as arsenic, antimony, germanium, fluorine and tin are also co-precipitated at this stage.

6.2.2.5 Purification

The main purpose of the purification stage is to remove the remaining metallic impurities. At the Risdon smelter, purification is carried out in two stages: primary purification and secondary purification. Primary purification is used to remove copper. Other metallic impurities including cadmium, nickel, and cobalt are precipitated at the secondary stage.

6.2.2.6 Electrolysis

The purified solution is then electrolysed in the cell room to form zinc metal. At the zinc plant, electrolysis is undertaken in lead-lined laminated wooden cells using aluminium sheet cathodes and lead anodes. To increase the efficiency of zinc deposition on the aluminium cathodes, small amounts of licorice, tutogen and antimony are added. It requires 48 to 72 hours for the required deposition of high purity zinc onto the aluminium cathodes, which are subsequently stripped and melted in electric induction furnaces for casting as zinc blocks.

6.3 Historical Environmental Control Measures Implemented at Pasminco-EZ

Throughout its operation PMEZ has been a significant contributor to the pollution in the Derwent Estuary through both its atmospheric and liquid emissions. The main sources of atmospheric emissions are electrolysis process, fugitive emissions, dust from stockpiles, raw material handling and road dust. Sulphur dioxide and particulates are primarily derived from the steam boilers, while most metal dust is emitted from the dross mill, casting bag-house and anode casting areas. Dust is also produced from a number of stockpiles at the wharf, and jarosite and primary leach residue dumps (Coughanowr, 1997).

Liquid emissions arise from several sources, but the greatest values are from the industrial process, and water and contaminated ground water discharges (Coughanowr, 1995: 69). According to Coughanowr (1997: 50), liquid emissions from the site contain Total Suspended Solids (TSS), sulphate (SO_4), ammonia (NH_4), and heavy metals, particularly Zn, Pb, Cd, Cu, Fe, Hg, As, F and Se. Before the treatment plant was commissioned, these heavy metals were discharged directly into the estuary.

The release of heavy metals into the estuary has been of concern since the plant began operating, but the dangers were not revealed to the public until an incident in 1970 when contaminated oysters taken from the estuary were consumed. In the incident, the zinc plant was blamed as the source of this

pollution (Ratkowsky et al., 1972). A study conducted by the CSIRO in 1972/73 confirmed that the oysters were toxic and the Risdon refinery was likely to be the principal source of the heavy metal pollution (Thrower and Eustace, 1973). As further evidence, Professor Bloom, from the University of Tasmania, conducted an intensive study in 1975 on the heavy metal concentrations in the sediments, fish and shellfish along the estuary. The result of the study reconfirmed that river sediments adjacent to the zinc refinery plant in Hobart were as high in heavy metals concentrations, especially mercury, as sections of the notorious Minamata Bay (Bloom, 1975: 19-21).

6.3.1 Jarosite

In response to this environmental issue, the zinc plant started to improve its technological process in 1971 with the commissioning of a Residue Treatment Plant (the jarosite process) to treat the significant amount of stockpiled solid waste (Alexander, 1992: 122). The useless portion from this process is known as jarosite. Jarosite is a mixture of iron, sulphate, ammonia, zinc, lead, cadmium, copper, mercury and arsenic. Approximately 240 000 tonnes per year of jarosite waste was produced (PMEZ, 1998: 2). Under a ministerial exemption in late 1973, jarosite was allowed to be dumped in the ocean 100 km south of Hobart (Coughanowr, 1997: 50). The impact of dumping jarosite on the aquatic ecosystem was investigated by the Department of Fisheries and Oceanography for several years. The studies did not find any evidence for concern (Department of Fisheries and Oceanography, 1994).

6.3.2 Paragoethite Process

The operators of the zinc plant have consistently expressed a commitment to improve the environmental performance of the plant, and have undertaken this through wide ranging research and pollution control activities. In late 1997 PMEZ reached an environmental milestone, when its jarosite process was replaced by the $40 milllion co-treatment (paragoethite process) (PMEZ, 1999). Co-treatment, or the paragoethite process, is a process where iron is precipitated from solution as hydrated ferric oxide (FeOOH) (for more detail of this process see Chapter 5 Section 5.4.4.2). The useless portion of sludge

formed (paragoethite) by the co-treatment is more inert and a safer product to dispose of compared with jarosite (PMEZ, 1998). The commissioning of this process eliminated the production of jarosite, allowing the company to meet its international commitments to the London Convention and cease its disposal of jarosite at sea (Hill, 1997).

6.3.3 Commissioning of Effluent Treatment Plant

With the commitment to improve its environmental management, a $ 2.5 million Contaminated Water Pond system was built in 1981. The system allows the removal of the majority of liquid emissions, and recycles them within the plant (Coughanowr, 1997; PMEZ, 1999:4; FINTAS 1981: 26; Hanslow, 1994: 87). With this commitment, the level of heavy metals in the Derwent Estuary has been significantly decreased compared with those results provided by Bloom in 1975 (Department of Environment, 1981).

In 1991 a $15 million effluent treatment plant and storm water recovery system was also commissioned. For many years the plant's effluent had been collected in contaminated water ponds which controlled the distribution of the contaminated effluent released into the environment. The new treatment plant receives approximately 2 000-5 000 kL/day of industrial processing effluent and storm water. Approximately 130 000 kL per day of effluent from the cleaning of the foreshore gas scrubbing system was also treated before being discharged into the estuary (PMEZ, 1999: 23). The treatment plant consists of the contaminated water storage pond, mercury removal, and lime neutralisation plants. A schematic of the effluent treatment system appears in Figure 6.3.

6.3.3.1 Contaminated Pond

A contaminated water system is used to collect and treat contaminated run-off and spills from gas cleaning sections of the sulphuric acid plants. The contaminated water system comprises neutralisers, settlers, a contaminated water pond and contaminated water head tank. Highly contaminated liquors from both sources are first neutralised in neutralisers with caustic soda or sodium hydroxide before overflowing into two settler tanks and then to the

contaminated water pond. Most suspended solids are settled in the settler tanks. The solids collected from the settler tanks are periodically removed and added to the underflow storage tank in leaching.

6.3.3.2 Mercury Removal Plant

A sulphide precipitation method is being used to treat liquor containing mercury from the acid plants. The treatment system consists of a storage tank and emergency storage tank, aluminium pellet columns, sulphide reactors, filter feed tank and filter press. In the process, liquors recovered from the storage tank are pumped through aluminium pellet columns. The liquor, containing mercury and sulphur gas, reacts with the aluminium pellets resulting in precipitation of the mercury in a solid form ($Hg^{2+} \rightarrow Hg^{\circ}$), and the sulphur gas being reduced to elemental sulphur and hydrogen sulphide. Additional precipitation of the mercury can occur when the hydrogen sulphide that forms during the reaction reacts with the mercury (Hg^{2+}). Most soluble arsenic compounds also precipitate during this stage.

The liquor, that now contains less than 0.1 mg/L of mercury, is then passed to two parallel sulphide reactors before gravitating to a filter feed tank. In these reactors additional mercury can be precipitated by the addition of a sulphide reagent. The filter feed tank provides additional surge capacity for the passing the liquor to the filter presses.

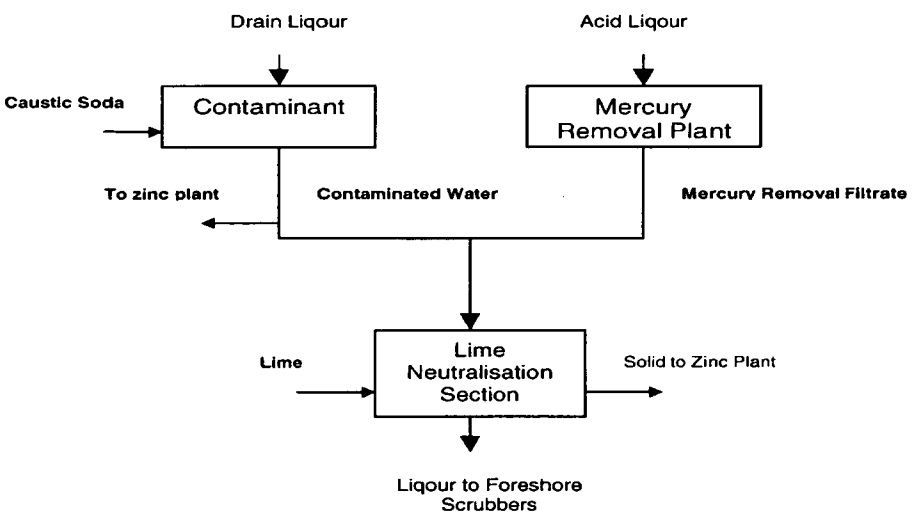
In the filter presses, mercury solids from the aluminium pellet column are manually removed and stored in plastic lined drums and are stockpiled on the foreshore. Filtrate from the presses passes to a SO_2 stripping tower. In the stripping tower, SO_2 gas is reduced to an acceptable concentration before being sent to the No.6 acid unit to be converted to sulphuric acid.

6.3.3.3 Lime Neutralisation Plant

Heavy metals contained in the liquor derived from the mercury removal plant, the contaminated water pond and from the cleaning of spent cooling towers in electrolysis are further removed and treated in the lime neutralisation plant.

During this process lime or calcium hydroxide is used to neutralise the liquor pH and to create a condition whereby heavy metal ions and calcium fluoride to precipitate as hydroxide and calcium fluoride. The heavy metal solids that precipitate in the process are filtered off as filter cakes. The valuable metals contained in these cakes are recovered in the zinc plant.

Figure 6.3. A brief description of effluent treatment system at the Risdon zinc refinery



(Source: PMEZ, 1999)

In addition to the effluent treatment process, various environmental management programs were also instituted to control the raw material and leach residue. A number of stockpiles of calcine, primary leach residue, concentrate and other materials that were stored in the open space around the site provided a source of air born particulate matter. According to EGS et al., (1992), about 18 000 to 20 000 tonnes of these materials were stockpiled during

the past 35 years. The introduction state-of-the-art processing and equipment, particularly the solution purification plant and the calcine handling system of the MOD1 modernisation program (installed between 1985 and 1992), have improved stockpile management on site as well as environmental performance. In addition, in 1997 the plant's management committed itself to reducing the plant's emissions into the environment by securing the stockpiles of jarosite behind the sea wall in landfill, and rehabilitating the Loogana and Inshallah area. The jarosite operation is completed and the rehabilitation program has been largely achieved (PMEZ, 1998).

Another significant environmental event was the commissioning of a new No.5 acid plant in 1992 to replace acid plants No.2 and No.3. This new acid plant, with an additional high efficiency foreshore scrubber, has reduced the plant's emission of sulphur dioxide gas by more than 90% (Dames and Moore, 1995b).

A new hydrometallurgy plant commissioned in October 1998 to recover stockpiled manganese dioxide was also expected to reduce the levels of manganese entering the river. Currently, the plant is operating on treating manganese dioxide arising from the electrolysis stage to produce manganese sulphate suitable for market. However, the plant is only treating current sources of manganese dioxide, and long-term management of the manganese dioxide residue stockpiles remains an issue (PMEZ, 1998).

In addition, the de-commissioning of the ammonia production plant, which ended the input of ammonia into the estuary, also resulted in improved productivity as well as pollution reduction from the plant.

In the last few decades the zinc plant's technological processes, and many environmental management issues, have been significantly improved. The process modification and waste management programs undertaken have led to the zinc plant overcoming many environmental concerns (see Table 6.1).

Table 6.1 Summary of major environmental improvements since 1990

Year	Description
1975	Commissioning of mercury removal plant
1991	Commissioning effluent treatment plant
1991/1992	Initiation of short-term and long-term stockpile management plan.
1993	Upgrade/construction of No.5 acid plant
1996	Commencement of re-treatment of manganese dioxide stockpile
1997	All stockpiles (except jarosite) covered or under sheds
1997	Jarosite production replaced by paragoethite, capable of co-treatment at Pasminco's Port Pirie smelter. Jarosite diposal in sea ceased in October 1997
1997	Loogana/Inshallah rehabilitation commenced. Some jarosite dumped at sea remainder secured in landfill. Primary leach residues shipped to Port Pirie for smelting

(Source: Coughanowr, 1997: 52; PMEZ, 1999).

These environmental improvement programs reflect Pasminco's implementation of BPEM principles as defined by the legislation in term of strategic plan to improve product and process design, to minimise waste production, and to effectively and efficiently treat and dispose of waste.

Despite the effort of the plant's operators to improve the plant's emissions record, there continues to be occasional environmental accidents. These are summarised in Table 6.2. For example, in 1988 60-110 litres of diesel from the acid plant leaked into the estuary. In 1996, a substantial load of zinc (9t) was diverted into the river without treatment (Coughanowr, 1997: 51).

Table 6.2 Selected environmental incidents since 1950

Years	Description of Events
1954	Domestic water tank in Lindisfarne, Montagu Bay and Bellerive are contaminated by fumes from EZ
1959	Hobart City Council notified public the pollution in Cornelian Bay
1966	Dead mullet discovered near Risdon EZ
1970	Consumption of contaminated oysters from Ralph's Bay
1973	Jarosite dumping at sea
1988	Oil spill (60–110 litres) from the acid plant into the estuary
1992	Fire in zinc dust stockpiles
	Spill of jarosite (10 tonnes) into the estuary (October)
	Spill of zinc and sulphuric solution (about 300 m^3) in to the estuary (November)
	Spill of 10-15 tonnes of sulphuric acid into the estuary (November)
1996	Spill of zinc (9 tonnes) into the estuary

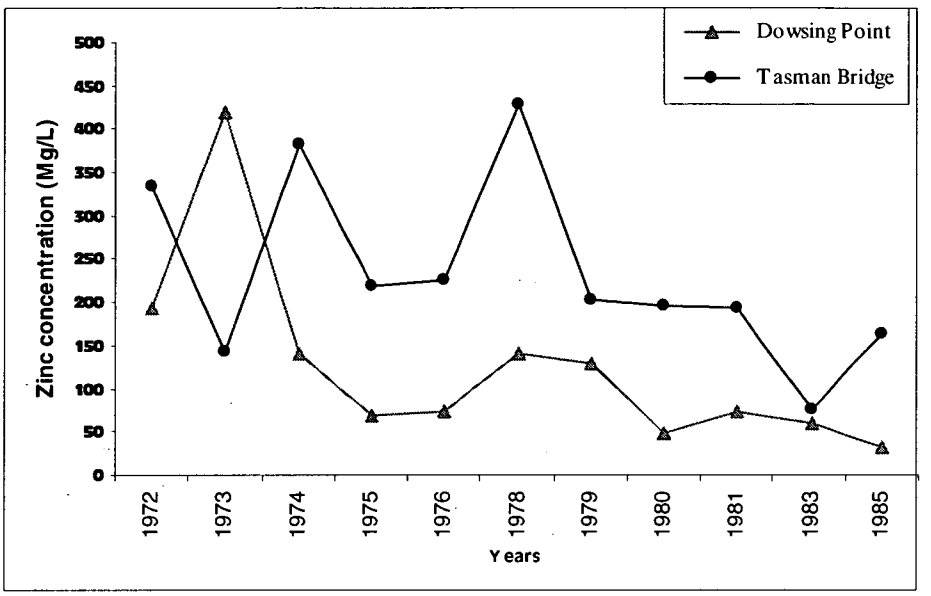
(Hanslow, 1994: 90 and Coughanowr, 1997: 51).

Between 1972 and 1985 the Department of Environment conducted annual studies on water quality along the Derwent estuary. In these studies, water samples were collected from 14 different sites throughout the estuary. The selected results of these studies are outlined in Figures 6.4 to 6.7. Based on these figures, it can be seen that the concentration of heavy metals in the estuary has significantly decreased since 1975.

Approximately 80% – 90% of heavy metals that were discharged into the estuary have been eliminated. The overall trends of heavy metal concentration in the estuary are outlined in Figures 6.4 to 6.7. The discussion of these trends

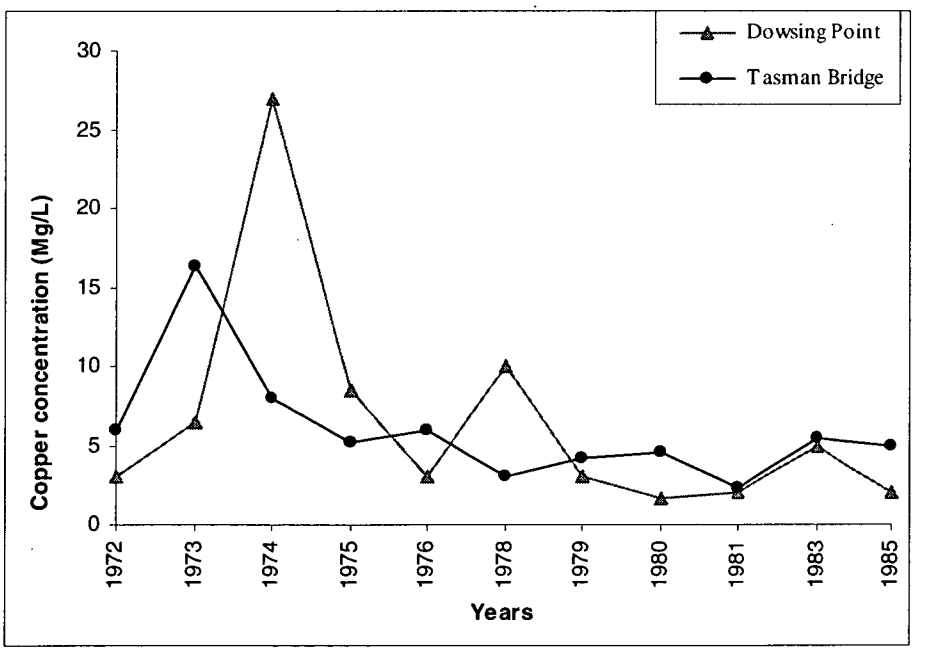
is, however, limited to the years 1976-1985 because the Department of Primary Industry, Water and Environment refuses publicly release any data for the following years.

Figure 6.4 Zinc concentrations in the Derwent Estuary



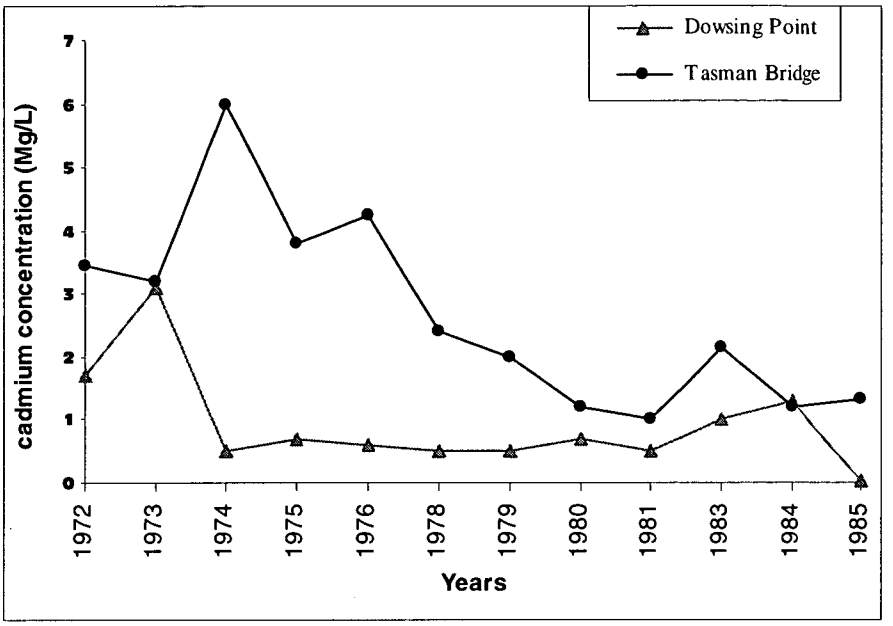
(Source: Department of the Environment, 1973, 75, 76, 79-86).

Figure 6.5 Copper concentrations in the Derwent Estuary



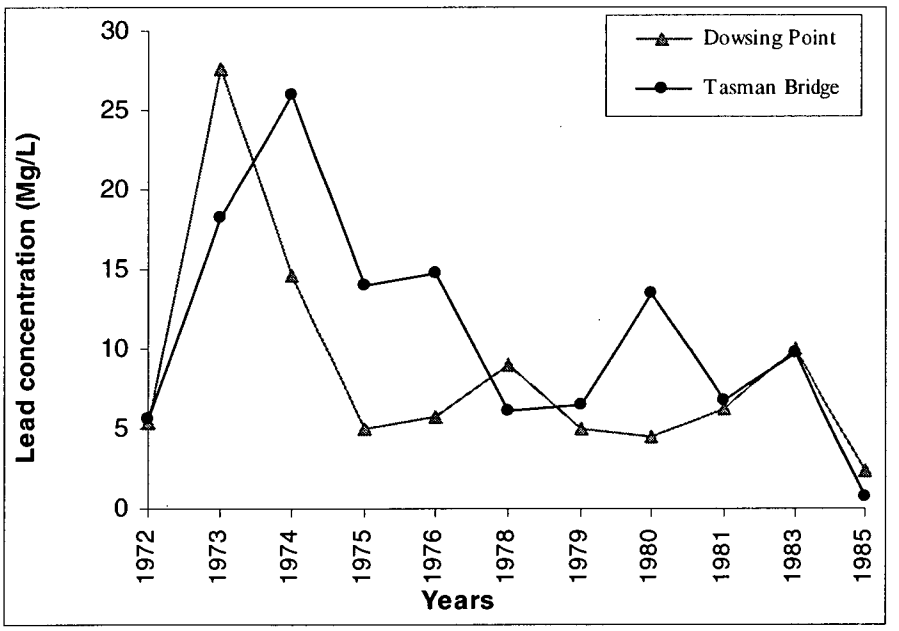
(Source: Department of the Environment, 1973, 75, 76, 79-86).

Figure 6.6 Cadmium concentrations in the Derwent Estuary



(Source: Department of the Environment, 1973, 75, 76, 79-86).

Figure 6.7 Lead concentrations in the Derwent Estuary



(Source: Department of the Environment, 1973, 75, 76, 79-86).

A study carried out by Langlois et al. 1987 on the effectiveness of PMEZ's mercury removal plant supported the Department's data. Using flathead fish as a biological indicator of the changing quantities of mercury in the Derwent river-bed sediments, Langlois et al. found showed that the average concentrations of heavy metals in samples taken from four different areas (north of the Tasman Bridge, the west bank of the Derwent River, the east bank of the Derwent River and Ralph's Bay) had declined markedly when compared with the 1976/77 data (Langlois et al., 1987).

Between 1993 and 1994 the CSIRO also conducted a monitoring program on $SnCL_2$- reactive (easily reducible), acid-labile and particulate mercury in the Derwent Estuary. The study showed that suspended particulate matter was the main source of mercury in the water column, with a strong correlation shown between acid labile and particulate concentrations. The study found that bottom waters in mid-reaches of the estuary displayed the highest acid-labile mercury concentrations. Values of up to 350 ng/L, which exceeded the national guideline of 100 ng/L, were detected. However, these values were significantly improved over those of 1600 ng/L reported by Bloom (1975). Further research confirmed the high mercury scavenging ability of suspended particulate matter in the Derwent Estuary, and indicated the ultimate fate of these particles is the dominant sink for inorganic mercury in the estuary.

Although the estuary remains polluted, environmental improvement programs implemented by PMEZ have had a significant impact on the quality of PMEZ's water discharges into the surrounding environment, and consequently, the Derwent Estuary's health has been significantly improved.

6.4 Environmental Management System at Pasminco Electrolytic Zinc Company

With the aim of continuing to improve its environmental performance in relation to its production processes, waste management and conservation of natural resources, PMEZ has recently established its own environmental management system. This EMS has been introduced within its existing safety

system and the quality management system, and reflects the ISO 14001 standard. The aims of this new environmental management system are to establish a process for setting objectives, planning, and identifying and monitoring environmental risks arising from operations. It is intended that the system will also facilitate the procedures laid down for the evaluating the organisation's environmental performance through internal auditing, and strengthen the overall environmental performance and commitment of the workforce to improving the integration of environmental projects with manufacturing processes.

To achieve these aims several environmental improvement programs have been conducted at the plant. These have comprised short and long-term training programs to raise the awareness of all employees of the need to implement environmentally related procedures such as daily and monthly internal reporting on environmental incidents and environmental performance, and to comply with the environmental management handbook. To evaluate and strengthen its environmental performance, PMEZ has also carried out environmental audits (internal environmental reviews) in cooperation with external bodies such as the State Government's environmental department, while the plant's superintendent has conducted public consultations to maximise the awareness of local communities of the environmental issues and challenges faced on the site. Another feature of the environmental management program implemented at PMEZ involves reducing, re-using and recycling waste materials. To further these aims the plant's management has commissioned a new hydrometallurgy plant to recover stockpiled manganese dioxide and reduce sulphur dioxide gas emissions from the plant. Perhaps the most innovative outcome, however, has been the project undertaken with a local cement manufacturer to incorporate the gypsum obtained from the effluent treatment into cement production. The company expects to provide between four and twelve thousand tonnes of gypsum per annum.

Integration of the new environmental management system is currently being developed. At present, PMEZ does not hold formal accreditation to ISO 14000.

Chapter 7
Overall Conclusions

This project has been undertaken to assess the level of acceptance and implementation of the concept of BPEM by two selected industries in Tasmania. Definitions of the concept of BPEM used in this assessment have been drawn from Tasmania's environment protection legislation and the Australian Manufacturing Council. Two case studies, Fletcher Challenge Paper and Pasminco EZ, have been undertaken as a small representation of Tasmanian industry, and the data in these case studies have been presented in a manner commensurate with these definitions.

7.1 Fletcher Challenge pulp and paper- Boyer mill

The conclusions that can be drawn from the study of FCP's Boyer mill is that the mill's operators have actively pursued the concept of BPEM, as defined in the legislation, and in so doing have significantly improved the mill's environmental performance.

The implementation of the concept of BPEM as defined in the legislation is most evident from the 1998 Annual Report which outlines the management and production objectives established in 1993. These objectives can be seen to incorporate the requirements of the legislation (see Chapter 2.1) in relation to setting environmental objectives and targets, identifying and assessing the environmental effects arising from the mills operations, and facilitating the planning, control, monitoring, auditing and review of the environmentally relevant operations of the mill.

The extent to which these objectives were achieved by 1998 is also articulated in the 1998 Environmental Management Report. According to the report 1995, environmental improvements at the Boyer mill have been significant. These are a result of the modification of the mill's manufacturing processes due to a modernisation program involving the installation of multidisc filters 'savealls' in paper No.2 and No.3 that resulted in the mill's water consumption being reduced from approximately 100 ML/day to 60 ML/day.

Another significant improvement stemming from the modernisation program has been the substitution of chlorine based bleaching, which resulted in waste containing organochlorines or dioxin (2,3,7,8 TCDD), with hydrogen based bleaching. The upgrading of the chlorine bleaching process has also allowed the caustic soda plant (used for producing chlorine) to be closed. This has eliminated approximately 85 kg of mercury per annum from the wastewater released into the Derwent Estuary. The commissioning of wastewater treatment plants (primary and secondary clarifiers) has also had a significant impact on the pollutant content of the mill's effluent, removing approximately 90% of wood fibre, 70% of BOD and 15%-20% of resin acids.

It must be noted that these improvements in environmental management have not only resulted from introducing cleaner production processes but also from an improved environmental management system. In this respect the objectives laid down in 1993 encompass, to differing degrees, those of the ISO 14000 series of standards, and can be seen to have played a central role in achieving BPEM.

However, based on the definition of the Australian Manufacturing Council, it is not possible to determine whether the mill has achieved BPEM or not. The literature review in Chapter 3 showed that some manufacturers in other countries are using process and pollution control technology that result in lower emissions of pollutants than is now the case at the Boyer mill. However, the AMC definition includes the words 'for the minimum economic investment'. It is not possible to say whether the cleaner technologies meet these economic criteria. Thus, without detailed economic analysis, it can only be concluded that the AMC definition can not be applied to the mill.

7.2 Pasminco Electrolytic Zinc Company

PMEZ is one of many Tasmanian industries that have continously and actively implemented the concept of BPEM as defined in Tasmanian legislation.

The implementation of the concept of BPEM can be clearly seen in many State Government and PMEZ reports, especially the Company's 1998 Environmental Management Report. This implementation has significantly improved the organisation's environmental performance.

In accordance with the requirements of the legislation (see Chapter 2.1), various objectives and targets for achieving better environmental performance were outlined in the 1996 Environmental Management Plan. These include planning, identifying and monitoring the environmental risks arising from the company's operations, and evaluating and auditing the organisation's environmental performance.

According to the Environmental Management Plan 1998, these objectives and targets have, in large part, been achieved (PMEZ, 1998:42). The fundamental reason for this achievement has been the implementation of the core principles of BPEM, that is, the modification of manufacturing processes and the introduction of an environmental management system. Central to achieving these objectives was the decommissioning of the jarosite process and the implementation of a new paragoethite process that allowed PMEZ to eliminate significant amounts of jarosite residues and, in so doing, comply with London Convention on the cessation of dumping at sea. Other improvements have resulted in a substantial reduction of heavy metals, manganese and ammonia, being released into the Derwent Estuary. These improvements involved the commissioning of effluent treatment plants for storm water and the discharge from the mercury treatment and lime neutralisation plants and the commissioning of a hydrometallurgy plant which allowed the recovery of stockpiled manganese dioxide. In addition, several environmental improvement programs have also been introduced at PMEZ. These have enabled the reuse of contaminated water for processing, and the incorporation of gypsum in cement powder production.

As with as the Boyer mill, although, PMEZ's environmental performance has improved significantly over the last decade, but based on the definition of

the Australian Manufacturing Council, it is not possible to determine whether PMEZ has achieved BPEM. The study on process and pollution control technology in this industry showed that some manufacturers are using superior technology to that employed at PMEZ. On the other hand, there is no economic analysis undertaken in this thesis. It is not possible, therefore, to say whether the cleaner technologies implemented at PMEZ meet the minimum economic investment required by the AMC. It can only concluded that the AMC's definition cannot be applied in this instance.

7.3 Conclusion

In conclusion, the study has shown that Fletcher Challenge's Boyer mill and the Pasminco-EZ refinery have, to differing degrees, implemented the concept of BPEM in accordance with the definition and requirements of Tasmania's resource management and planning legislation. The companies' implementation of the concept has involved the introduction of new, and modifications to existing, technology, to enable cleaner production, and the establishing of environmental management systems to better manage the impacts of their activities on the environment.

Substantial improvements in Fletcher Challenge's and Pasminco-EZ's environmental performance and management have been witnessed as a result of their pursuit of BPEM. These improvements have been reflected in the increasing quality of the Derwent Estuary water column and sediments, and the recycling and re-use of production wastes.

Tasmanian industry has been obliged to meet specific statutory objectives intended to promote BPEM. Varying degrees of compliance with these objectives, and the substantial improvement in the environmental performance of the two companies researched for this work, suggest the definition of BPEM in the legislation to be effective. In contrast, the definition promoted by the Australian Manufacturing Council, largely because of its absence of prescription, is limited in its use for either facilitating or assessing industry's efforts towards establishing BPEM.

This research has raised many questions outside the context of this work which need investigating. For example, the conscious effort by these two companies to upgrade their environmental performance coincided with the formulation/introduction of Tasmania's new resource management legislation in the early 1990s. However, at this time the management of Fletcher Challenge faced serious economic competitiveness issues and recognised the need for greater production efficiency. Given the improvements in environmental performance by these companies, what role has the legislation played in their adoption of BPEM, and how effective is the legislation as Best Practice Environmental Regulation?

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